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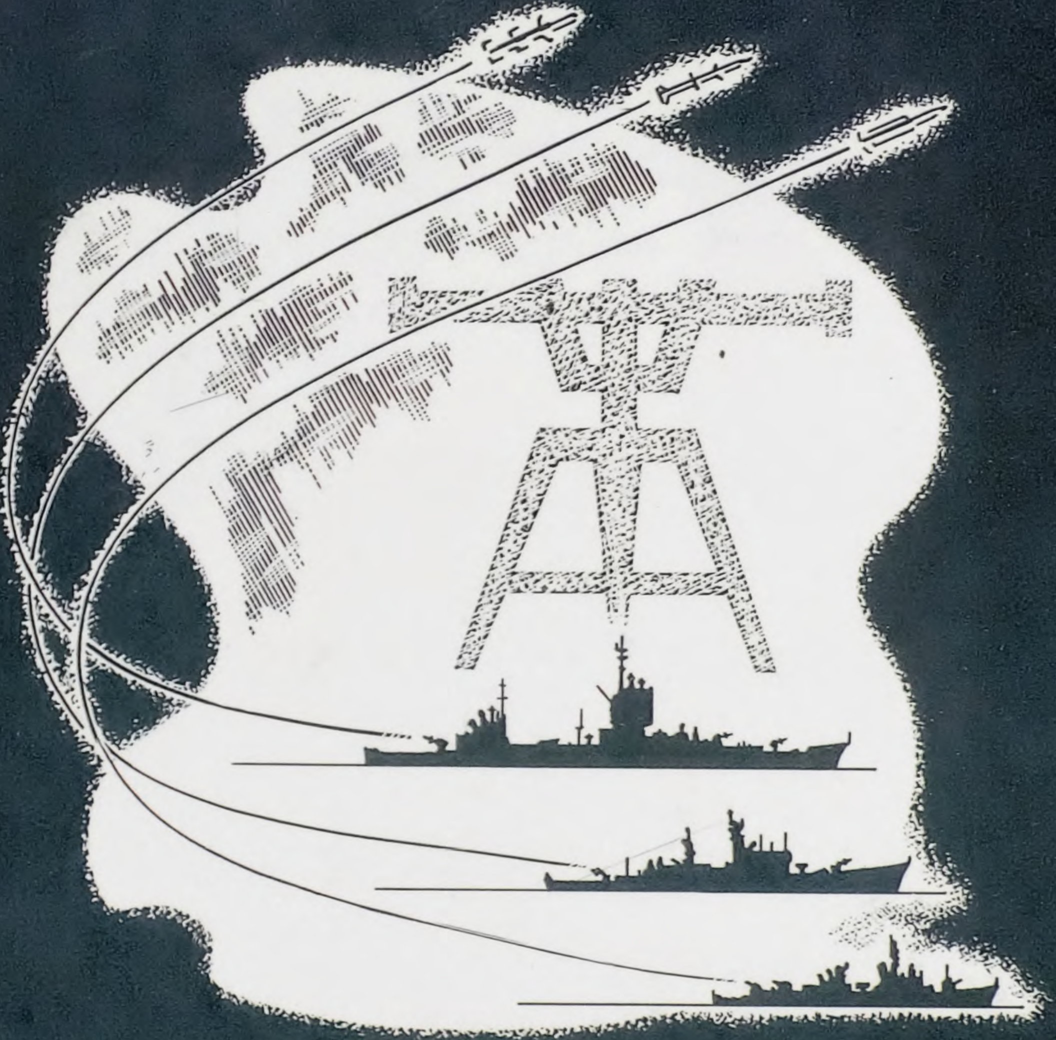

FIRE CONTROL TECHNICIAN M 3&2

NAVAL EDUCATION AND TRAINING COMMAND

RATE TRAINING MANUAL NAVEDTRA 10209-A

Twin Cities Campus

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PREFACE

This Rate Training Manual will serve as an aid for enlisted men of the U.S. Navy and U.S. Naval Reserve who are preparing for increased responsibility in the rate of Fire Control Technician M 3 and 2.

One of a series of Rate Training Manuals, this manual is designed to give enlisted men background information necessary for the proper performance of their duties and training in consonance with the Navy's goal of training for victory at sea.

The predominant factor in the selection of the content of this publication has been the Manual of Qualifications for Advancement, NAVPERS 18068-C.

This book was prepared by the Naval Education and Training Program Development Center for the Naval Education and Training Command. Special credit is given to the Naval Ship Weapon Systems Engineering Station, Port Hueneme, California; Naval Guided Missile School, Dam Neck, Virginia Beach, Virginia; and the Naval Examining Center (disestablished), Naval Training Center, Great Lakes, Illinois.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

THE FIRE CONTROL TECHNICIAN (MISSILE)

INTRODUCTION

This training manual has been prepared for men of the Navy and of the Naval Reserve who are studying for advancement to the rates of Fire Control Technician (Missile) 3 and Fire Control Technician (Missile) 2. The Fire Control Technician (Missile) qualifications used as a guide in the preparation of this training manual are those contained in Revision C, Change 1, of the Manual of Qualifications for Advancement, NavPers 18068-C. This rate training manual is based on the latest change to the quals. The subject matter in this training manual has been organized to give you a systematic understanding of your job.

Chapter 2 introduces the guided missile and the basic methods of controlling its flight. Chapter 3 provides an overview of a representative shipboard weapons system and presents elements of the missile fire control problem. Chapter 4 contains basic information on missile handling and testing, and provides both basic and specific information on ordnance safety precautions.

Basic mechanical, electromechanical, and electrical component parts common to Navy missile systems are the subject material of chapter 5. Chapter 6 discusses the basic principles of analog computers and computing mechanisms. Chapter 7 introduces you to digital computer techniques and devices. Chapter 8 contains basic information on fire control radars. Chapter 9 incorporates fundamental information on servomechanisms. Chapter 10 considers gyroscopes and some of their applications.

Chapter 11 highlights the use of synchros, resolvers, and digital devices in intraship data transmission systems. General purpose test equipment commonly used by the missile fire control technician is presented in chapter 12. Administrative requirements are presented in chapter 13. Finally, chapter 14 covers maintenance techniques currently being employed aboard Navy surface missile ships.

Completion of this manual, applicable to all surface missile system areas, prepares you for one of three supplementary courses which will provide you with specific knowledge concerning the surface missile system to which you are assigned. The subject matter of the 3 supplementary courses will be as follows:

Supplement 1 — Terrier weapon system equipment.

Supplement 2 — Tartar weapon system equipment and Basic Point Defense Surface Missile System.

Supplement 3 — Talos weapon system equipment.

Completion of the applicable supplementary course is essential with regard to your preparation for advancement in rating.

THE ENLISTED RATING STRUCTURE

The two main types of ratings in the present enlisted rating structure, are general ratings and service ratings.

GENERAL RATINGS identify broad occupational fields or related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

SERVICE RATINGS identify subdivisions or specialties within a general ratings. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

THE FIRE CONTROL TECHNICIAN RATING

As a Fire Control Technician, you must learn the fire control problem to better enable you to visualize the functions of the equipment in a fire control system. But knowing the theory behind the problem and the functions of the equipment is only part of your job. You'll have to practice many skills to maintain the equipment.

You must be a mechanic so that you can maintain, adjust, and repair fire control equipment. You must learn the principles of mechanics and how to use handtools, gages, and measuring instruments effectively.

You must be an electrician, for you'll be working with electric motors and generators, switchboards, and control devices for heavy equipments such as directors and radar sets.

You must be an electronics technician because you will repair and maintain missile fire control radars, weapon direction equipment, computers, and other instruments containing vacuum tube and transistor circuitry.

Maintenance and repair of fire control equipment will be only part of your job. You must become familiar with every knob, dial, and control at your battle station, for you'll be operating the equipment located there.

What kind of men make good Fire Control Technicians? What kind of mental equipment do you need to make the grade? Before the Navy approved you as a striker for FT3, it gave you a battery of tests. Because you passed those tests and got exceptionally high marks, we know you have the ability to learn quickly, and to master a large body of technical knowledge. Also, you have mechanical aptitude; if you haven't already developed a high degree of mechanical skill, you have what it takes to acquire it.

In order to become a valuable Fire Control Technician, you'll need other things besides a sharp brain and skillful hands. You must be conscientious and completely reliable. To illustrate why these qualities are so important, let's suppose for a minute that you are aboard a destroyer in wartime, and that you have prepared a guided missile fire control system for firing. Assume that, because of carelessness, you've skipped one of the necessary adjustments, or have done it sloppily. What happens when you launch that missile at an enemy plane? Instead of riding the guidance beam to the target, the missile sets a course for the bottom of the sea. There are other things that might happen to a malfunctioning missile, but the result would be the same—the enemy escapes. The one that got away could come back and cause the death of your own ship.

But don't worry; nothing like that is going to happen to you. Why not? Because when you prepare a fire control system for firing, you'll make ALL the adjustments, and you'll make them carefully and skillfully. Before the Navy gives you the responsibility of preparing a system for firing, you'll have to prove your dependability.

TYPES OF RATING

The fire control technician rating structure is:

1. A general rating at pay grades E-8 and E-9.

2. Three service ratings — FTM (Missile Fire Control), FTG (Gun Fire Control), and FTB (Ballistic Missile Fire Control) in pay grades E-4 through E-7.

As you can see, the fire control service ratings are divided by the type of weapons being controlled. As an FTM, your weapon will be one of the Surface Missile System family of missiles. This leads into a discussion of the Navy Enlisted Classification (NEC) codes.

Navy Enlisted Classification (NEC) Codes

The Manual of Enlisted Classifications, NavPers 15105 (latest rev.), lists the specialty groups within the ratings. NEC code numbers have been assigned to indicate special training requirements within the rating. The NEC code numbers subdivide the FT rating by the types of fire control systems or equipment. There are approximately 28 NEC code numbers assigned to the FTM rating. Normally, you will be assigned duty by your NEC code number to a ship with the designated system or equipment installed.

As a FTM 3 or FTM 2, you probably will be assigned to a billet aboard ship which calls for an equipment specialist. This, however, does not relieve you of the responsibility of acquiring systems knowledge of the major surface missile system areas. Hopefully, you will be impressed with this fact prior to your first examination for advancement in rate.

DUTIES AND RESPONSIBILITIES

Everyone wants to know what a job is like before he chooses it as his vocation. As you already know, fire control equipment is maintained, repaired, and usually operated by fire control personnel. The degree of responsibility and complexity of maintenance will depend upon your rate. Besides the occupational or professional duties, you will have certain military duties, as do all ratings in the Navy. These military duties include the manning of battle stations, watch standing, and other assignments related to the requirements for naval operations, management, and security. This course is concerned with your professional (technical) duties—NOT your military duties.

Missile fire control technicians operate, test, maintain, and repair shipboard missile fire control systems (including weapons direction systems and three-coordinate search radars), missiles, and associated support equipment.

In order to ensure the proper functioning of their assigned equipment, FTMs must make a detailed analysis of mechancial, electrical, and electronic failures. They must be familiar with system and equipment alignment procedures.

As you increase your skill and knowledge, the Navy will add to your responsibility. Soon you will become a FTM 3 or FTM 2. As such, you will be a leader and a teacher. You will be in a position to not only lead others, but you will be a molder of fire control strikers.

Third class is only the first step up the ladder of success. As you know, there is no limit to how far you can go in the Navy. Your division officer or weapons officer may have started his career as a fire control striker. Remember, the path to advancement is open. The rest is up to you.

As a Fire Control Technician you will have an important practical part to play in your shipboard leadership program. You will take charge of a group of strikers. This will put you in a position of leadership. You will have two responsibilites—to accomplish a mission and to take care of your men.

General Order 21, promulgated 17 May 1958, stressed the need to develop and improve our naval leadership in all its aspects: inspirational, technical, and moral. The revised General Order 21 directs our efforts toward, achieving an ever-improving state of combat readiness through effective naval leadership.

The general principles and techniques of leadership are fully discussed in Military Requirements for PO 3 & 2, NavPers 10056-C. However, let's do a little thinking about how you can help to carry out General Order 21 on a day-to-day basis.

Assume for a moment that your mission aboard ship is to maintain a fire control system, and you have strikers to assist you. Now a big part of your job is to learn everything you can about the system and to pass on your knowledge to your men. Technical competence is a major aspect of good leadership. But being a skilled technican is not enough. You must inspire your strikers to do their work as efficiently as possible.

A national characteristic of the American fighting man is that he wants to know the reason why he is called upon to perform certain tasks. You must explain to your strikers the importance of their work and how it affects the overall fighting efficiency of your ship. Make the smallest mechanical task take on the nobility of a cause. During missile battery exercises or drills make them feel they are winning a war, not just turning knobs on equipment. Keep in mind they are the men who will fight by your side in combat. When led with courage, spirit, and intelligence, they will fight as willingly and as efficiently as any fighter in the world. But it is up to you to provide inspiration so that it will seep down to them.

To inspire your strikers, and others, you must have a strong moral character. Some of the character traits you can develop by conscientious study and practice are loyalty, integrity, and quiet self-confidence.

Loyalty is one of the most essential factors of leadership. Experienced officers and petty officers say that they would rather have a loyal man who is not an excellent worker than a disloyal man who does excellent work. Loyalty to the country, to the Navy, to your ship, to your division, to your chief, to your senior petty officer, and to the men who work with and for you—these are the prime requisites of leadership. The surest way to get the respect and loyalty of your men is to be loyal yourself.

Every time you feel the urge to criticize the handling of your ship's affairs, stop short! You are part, and an important part, of your ship. How can you expect your strikers to be loyal if you are not?

Deal with your men squarely and honestly. If you do, you will win and hold their respect. Be dependable. This mark of integrity involves keeping promises promptly. A reputation of being a "square shooter" is worth every effort on your part. Help to build this reputation early by not tolerating "gun-decking" or other methods of falsifying reports.

Good leaders have a quiet self-confidence (not an arrogant or cocky manner) based on thorough knowledge of the job and in a belief in their own ability. Confidence begets confidence. If you have confidence in yourself, you can inspire confidence in your men.

ADVANCEMENT IN RATING

Some of the rewards of advancement in rating are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancing in rating are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement in rating, you increase your value to the Navy in two ways. First, you become more valuable as a specialist in your own rating. And second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement in rating? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.

2. Complete the required military and occupational training manuals.

3. Demonstrate your ability to perform all the PRACTICAL requirements for advancement by completing the Record of Practical Factors, NavPers 1414/1.

4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.

5. Demonstrate your KNOWLEDGE by passing written examinations on the occupational and military qualification standards for advancement in rating.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-2 gives this information for inactive duty personnel.

Remember that the qualifications for advancement can change. Check with your division officer or training officer to be sure that you know the most recent qualifications.

Advancement in rate is not automatic. Even though you have met all the requirements, including passing the written examinations, you may not be able to "sew on the crow" or "add a stripe." The number of men in each rate and rating is controlled on a Navywide basis. Therefore, the number of men that may be advanced is limited by the number of vacancies that exist. When the number of men passing the examination exceeds the number of vacancies, some system must be used to determine which men may be advanced and which may not. The system used is the "final multiple"

E-4 time in service requirements changed by DOD effective 1 July 1975 for advancement to E-4 TIS requirements are increased from 21 months minimum to 2 years.

REQUIREMENTS *	E1 to E2	E2 to E3	# E3 to E4	# E4 to E5	E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of Recruit Training.	8 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4. 3 years time in service.	24 mos. as E-5. 6 years time in service.	36 mos. as E-6. 8 years time in service.	36 mos. as E-7. 8 of 11 years time in service must be enlisted.	24 mos. as E-8. 10 of 13 years time in service must be enlisted.
SCHOOL	Recruit Training. (C.O. may advance up to 10% of graduating class.)	▨	Class A for PR3, DT3, PT3, AME 3, HM 3, PN 3, FTB 3, MT 3,	▨	▨	Class B for AGC, MUC, MNC.††		
PRACTICAL FACTORS	Locally prepared check-offs.	Record of Practical Factors, NavEdTra 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST	▨	▨	Specified ratings must complete applicable performance tests before taking examinations.				▨	▨
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS **	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.			Navy-wide selection board.		
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	▨	Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavEdTra 10052 (current edition).					Nonresident career courses and recommended reading. See NavEdTra 10052 (current edition).	
AUTHORIZATION	Commanding Officer		NAVEDTRAPRODEVCEN					

* All advancements require commanding officer's recommendation.
† 2 years obligated service required for E-7, E-8, and E-9.
# Military leadership exam required for E-4 and E-5.
** For E-2 to E-3, NAVEDTRAPRODEVCEN exams or locally prepared tests may be used.
†† Waived for qualified EOD personnel.

Figure 1-1.—Active duty advancement requirements.

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	8 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 8 yrs service	36 mos. with total 11 yrs service	24 mos. with total 13 yrs service
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavEdTra 1414/1, must be completed for all advancements.							
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO advancements. Also pass Military Leadership Exam for E-4 and E-5.				Standard Exam, Selection Board.	
AUTHORIZATION	Commanding Officer		NAVEDTRA PRODEVCEN					

*Recommendation by commanding officer required for all advancements.
† Active duty periods may be substituted for training duty.

Figure 1-2.—Inactive duty advancement requirements.

and is a combination of three types of advancement systems.

Merit rating system
Personnel testing system
Longevity, or seniority, system

The Navy's system provides credit for performance, knowledge, and seniority, and, while it cannot guarantee that any one person will be advanced, it does guarantee that all men within a particular rating will have equal advancement opportunity.

A change in promotion policy, starting with the August 1974 examinations, changed the Passed-But-Not-Advanced (PNA) Factor to the High Quality Bonus Point (HQP) factor. Under this policy, a man that passed the examination, but was not advanced can gain points toward promotion in his next attempt. Up to three multiple points can be gained in a single promotion period. The points can then be accumulated over six promotion periods up to a maximum of 15. The addition of the HQP factor, with its 15-point maximum, raises the number of points possible on an examination multiple from 185 to 200. This gives the examinee added incentive to keep trying for promotion in spite of repeated failure to gain a stripe because of quota limitations.

The following factors are considered in computing the final multiple:

- EXAMINATION
- PERFORMANCE
  Leadership
  All other
- EXPERIENCE
  Awards and Medals
  Total Active Service
  Time in present grade
  High Quality Points

All of the above information (except the examination score and the HPQ factor) is submitted to the Naval Examining Center with your examination answer sheet. After grading, the examination scores, for those passing, and the HPQ points (additional points awarded to those who previously passed the examination but were not advanced) are added to the other factors to arrive at the final multiple. A precedence list, which is based on final multiples, is then prepared for each pay grade within each rating. Advancement authorizations are then issued, beginning at the top of the list, for the number of men needed to fill the existing vacancies.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare advancement in rating? You must study the qualifications for advancement, work on the practical factors, study the required Rate Training Manuals, and study other material that is required for advancement in your rating. To prepare for advancement, you will need to be familiar with (1) the Quals Manual, (2) the Record of Practical Factors, (3) a NavEdTra publication called Bibliography for Advancement Study, NavEdTra 10052, and (4) applicable Rate Training Manuals. The following sections describe them and give you some practical suggestions on how to use them in preparing for advancement.

Quals Manual

The Manual of Qualifications for Advancement, NavPers 18068-C (with changes), gives the minimum occupational and military qualification standards for advancement to each rate within each rating. This manual is uaually called the "Quals Manual," and the qualifications themselves are often called "quals." The qualification standards are of two general types: (1) military qualification standards and (2) occupational qualification standards.

MILITARY STANDARDS are requirements that apply to most ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in most ratings.

OCCUPATIONAL STANDARDS are requirements that are directly related to the work of each rating.

Both the military requirements and the occupational qualification standards are divided into subject matter groups; then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rating.

In most subject matter areas, you will find both practical factor and knowledge factor qualifications. In some subject matter areas, you may find only one or the other. It is important to remember that there are some knowledge aspects to all practical factors, and some pracical aspects to most knowledge factors. Therefore, even if the Quals Manual indicates that there are no knowledge factors for a given subject matter area, you may still expect to find examination questions dealing with the knowledge aspects of the practical factors listed in that subject matter area.

You are required to pass a Navywide military/leadership examination for E-4 or E-5, as appropriate, before you take the occupational examinations. The military/leadership examinations are administered on a schedule determined by your commanding officer. Candidates are required to pass the applicable military/leadership examination only once. Each of these examinations consists of 100 questions based on information contained in Military Requirements for Petty Officers 3 and 2, NavEdTra 10056 (current edition) and in other publications listed in Bibliography for Advancement Study, NavEdTra 10052 (current edition).

The Navywide occupational examinations for pay grades E-4 and E-5 will contain 150 questions related to occupational areas of your rating.

If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

The Quals Manual is kept current by means of changes. The occupational qualifications for your rating which are covered in this training manual were current at the time the manual was printed. By the time you are studying this manual, however, the quals for your rating may have been changed. Never trust any set of quals until you have checked it against an UP-TO-DATE copy in the Quals Manual.

Record of Practical Factors

Before you can take the servicewide examination for advancement in rating, there must be an entry in your service record to show that you have qualified in the practical factors of both the military qualifications and the occupational qualifications.

The RECORD OF PRACTICAL FACTORS, mentioned earlier, is used to keep a record of your practical factor qualifications. This form is available for each rating. The form lists all practical factors, both military and occupational. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for Advancement, and revised forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the Quals Manual. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement.

Until completed, the NavPers 1414/1 is usually held by your division officer; after completion, it is forwarded to the personnel office for insertion in your service record. If you are transferred before qualifying in all practical factors, the incomplete form should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you may be required to start all over again and requalify in the practical factors which have already been checked off.

NavEdTra 10052

Bibliography for Advancement Study, NavEdTra 10052 (revised), is a very important publication for anyone preparing for advancement in rating. This bibliography lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement in rating. NavEdTra 10052 is revised and issued once each year by the Naval Education and Training Support Command. Each revised edition is identified by a letter following the NavEdTra number. When using this publication, be SURE that you have the most recent edition.

If extensive changes in qualifications occur in any rating between the annual revisions of NavEdTra 10052, a supplementary list of study material may be issued in the form of a NavEdTra Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications for your rating. If changes have been made, see if a NavEdTra Notice has been issued to supplement NavEdTra 10052 for your rating.

The required and recommended references are listed by rate level in NavEdTra 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class; but remember that you are also responsible for the references listed at the third class level.

In using NavEdTra 10052, you will notice that some Rate Training Manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY — that is, it must be completed at the indicated rate level before you can be eligible to take the servicewide examination for advancement in rating. Each mandatory manual may be completed by (1) passing the appropriate nonresident career course that is based on the mandatory training manual; (2) passing locally prepared tests based on the information given in the Rate Training Manual; or (3) in some cases, successfully completing an appropriate Class A course.

Do not overlook the section of NavEdTra 10052 which lists the required and recommended references relating to the military qualification standards for advancement. Personnel of ALL ratings must complete the mandatory military requirements Rate Training Manual for the appropriate rate level before they can be eligible to advance in rating.

The references in NavEdTra 10052 which are recommended but not mandatory should also be studied carefully, ALL references listed in NavEdTra 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. RATING MANUALS (such as this one) are prepared for most enlisted ratings. A rating training manual gives information that is directly related to the occupational qualifications of ONE rating. SUBJECT MATTER MANUALS or BASIC MANUALS give information that applies to more than one rating.

Rate Training Manuals are revised from time to time to keep them up to date technically. The revision of a Rate Training Manual is identified by a letter following the NavEdTra number. You can tell whether any particular copy of a Rate Training Manual is the latest edition by checking the NavEdTra number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavEdTra 10061. (NavEdTra 10061 is actually a catalog that lists all current Rate Training Manuals and nonresident career courses; you will find this catalog useful in planning your study program.)

Rate Training Manuals are designed to help you prepare for advancement in rating. The following suggestions may help to make the best use of this manual and other Navy training publications when you are preparing for advancement in rating.

1. Study the military qualifications and the occupational qualifications for your rating before you study the Rate Training Manual, and refer to the quals frequently as you study. Remember, you are studying the Rate Training Manual primarily in order to meet these quals.

2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can plan to study at the same time each day. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the Rate Training Manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the book without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the Rate Training Manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book. As you look through the book in this way, ask yourself some questions:

- What do I need to learn about this?
- What do I already know about this?
- How is this information related to information given in other chapters?
- How is this information related to the qualifications for advancement in rating?

5. When you have a general idea of what is in the Rate Training Manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit — it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will vary. If you know the subject well, or if the material is easy, you can

cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit—chapter, section, or subsection—write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the Rate Training Manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the Rate Training Manual, write down the main ideas that you have gotten from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use Enlisted Nonresident Career Courses whenever you can. The nonresident career courses are based on Rate Training Manuals or on other appropriate tests. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing a Nonresident Career Course. You will probably find it helpful to take other nonresident career courses, as well as those based on mandatory training manuals. Taking a nonresident career course helps you to master the information given in the training manual, and also helps you to see how much you have learned.

10. Think of your future as you study Rate Training Manuals. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn will help you both now and later.

The highly speicalized skills required of you as a Fire Control Technician (Missile) must be based on knowledge drawn from a variety of technical fields. Success in acquiring the knowledge, and thus the skills, does not depend simply upon your willingness to read large quantities of technical material. What is more important is the extent to which you are able to dig out the important idea, to understand how these ideas fit into patterns, and to see how they apply to your work. By improving your method of study, you can bring about a significant increase in your understanding, especially as the new method develops into a study habit.

SOURCE OF INFORMATION

Besides Rate Training Manuals, NavEdTra 10052 lists official publications on which you may be examined. You should not only study the sections required, but should become as familiar as possible with all publications you use.

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the occupational qualifications of your rating.

PUBLICATIONS YOU SHOULD KNOW

Training Publications

Some of the training publications that you will need to study or refer to as you prepare for advancement have been discussed earlier in this chapter. Some additional training publications that you will find useful are listed here.

Mathematics, Volume 1, NavPers 10069-C
Mathematics, Volume 2, NavPers 10070-B
Mathematics, Volume 3, NavPers 10073-A
Basic Electricity, NavPers 10086-B
Basic Electronics, NavPers 10087-C
Fluid Power, NavPers 16193-B

All NavPers publications and training aids produced for training purposes were transferred on 15 February 1972 from Chief of Naval Personnel control to Chief of Naval Education and Training cognizance. "NavEdTra" will replace "NavPers" for the identifying designator. It is anticipated that 5 years will be required to phase out all existing NavPers printed material.

NAVORDSYSCOM Publications

Ordnance Pamphlets (OPs) are issued by the former Bureau of Naval Weapons, now the Naval Ordnance System Command (NAVORDSYSCOM). An example of an OP of importance to you is OP 2818, Antijamming Manual for Shipboard Tracking Radars.

Chapter 12 of this Rate Training Manual discusses most of the publications you will use. Detailed information you need for advancement and for everyday work is contained in them. Some are subject to change or revision from time to time — some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance in rating; it is likely to be a waste of time, and may even be seriously misleading.

Other Sources

The manufacturer's technical manuals that are furnished with many items of equipment are valuable sources of information on operation, maintenance, and repair. Occasionally, a manufacturer's technical manual is the only source of information available on a particular piece of equipment. In any event, they supplement your official Navy publications so they are an essential item of your technical reference material.

The United States Armed Forces Institute (USAFI) provides opportunities for military personnel to continue their education while they are on active duty with the Armed Forces of the United States. Many USAFI courses offered provide you with the means of further preparing yourself for advancement. See your education officer about the details of taking courses. If there are enough interested students aboard ship (or on the base) a group study course can be arranged.

TRAINING FILMS

Training films available to naval personnel are a valuable source of supplementary information on many technical subjects. Training films are listed in the United States Navy Film Catalog, NavAir 10-777 (formerly NavWeps 10-1-777), published in 1969. Copies may be ordered in accordance with the Navy Stock List of Forms and Publications, NavSup 2002. Monthly supplements to the Film Catalog are distributed to catalog holders.

When selecting a film, note its date of issue listed in the Film Catalog. As you know, procedures sometimes change rapidly. Thus some films become obsolete rapidly. If a film is obsolete only in part, it may sometimes be shown effectively if before or during its showing you carefully point out to trainees the procedures that have changed.

CHAPTER 2

THE GUIDED MISSILE

MISSILE FUNDAMENTALS

This chapter presents the physical and functional characteristics of guided missiles. The information is presented at an elementary level and, for the most part, is applicable to all guided missiles. Bear in mind, however, that you are striving for knowledge of the basic principles and concepts underlying the operation of missiles employed by the Surface Missile Systems (SMS) of the Navy. Therefore, the focus of attention is directed toward SMS missiles.

After studying this chapter, you will know what a guided missile is, how it is classified, and how it is guided, stabilized, and propelled. Finally, you will know the essential components required for a guided missile to perform its mission.

Any object that can be hurled, projected, launched or propelled into flight may be called a missile. This definition includes stones, arrows, projectiles, bombs, torpedoes, rockets, and airplanes. The scientific progress made in rocketry, jet propulsion, electronics, and aerodynamics not only has increased the range of the missile but now allows it to be controlled or guided in its flight. A tactical guided missile carries an explosive warhead and some means of controlling its own trajectory or flight path.

Generally, a guided missile system is considered to have 5 subsystems. These are the air frame (structure), propulsion, flight control, guidance, and warhead.

The warhead is the primary subsystem of the missile (considering the missile itself to be the system), as the end result (target kill) is accomplished directly by its destructive energy output. The main missile structure is the body or fuselage which not only carries and protects the warhead and allied elements from the forces or pressures that will be exerted on them, but has aerodynamic surfaces attached to it that are used to stabilize the missile and to control for errors in its flight trajectory. In addition, the structure contains a subsystem to control these surfaces and a means of propulsion to move the missile from its launch point to its target. To correct for flight path errors and/or to allow the missile to seek out and destroy an enemy target, a guidance subsystem is added.

MISSILE REQUIREMENTS

Guided missiles were developed to overcome the limitations of older weapons. The development of conventional weapons has reached a point where tremendous cost and effort are necessary to produce only a small improvement in their performance. The primary mission of a guided missile is the same as that of its counterpart, the conventional weapon. The following examples show some of the missions and the advantages of using guided missiles to supplement or replace them.

Air-to-Surface

Air-to-surface guided missiles are greatly superior to conventional bombs. The aircraft dropping bombs is limited in the performance of its mission by weather, interception by enemy aircraft, antiaircraft artillery, and, in some cases, the maneuvering of the target during the fall of the bombs. By building bombers that can fly higher and faster, antiaircraft artillery and fighter interception can be evaded; but the accuracy of the bombs would be greatly reduced, and the weather would have a greater effect. By replacing the bombs with guided missiles which can be launched at greater ranges and which contain a guidance system that will home on the target regardless of weather and target maneuvers, the destructive effect can be greatly increased, and the danger of enemy countermeasures greatly reduced.

Surface-to-Air

Now consider your side of the problem. As a FTM, you are involved with a missile that is used primarily as a surface-to-air weapon. Obviously, you want the operational capabilities of your ship's weapons to exceed those of the enemy. An aircraft, for example, must be destroyed before it reaches its weapon-release range, called its standoff range. The shiplaunched guided missile is greatly superior to an antiaircraft gun in range, maximum altitude, and accuracy. As a result, it can destroy an enemy aircraft beyond the range of a gun.

Air-to-Air

In air-to-air combat, guided missiles greatly increase the striking range and destructive power of aircraft.

The interceptor aircraft of the past relied primarily on its speed advantage to maneuver into position where its short-range weapons were effective. Against modern jet bombers or missiles, interceptors lose their speed advantage, thus making it difficult, if not impossible for them to maneuver into position for attack. By arming them with long-range missiles which travel at supersonic speeds, the interceptor will be capable of combating the high-speed. high-altitude weapons of modern warfare.

Surface-to-Surface

The average person, when thinking of a surface-to-surface missile, will visualize the intercontinental ballistic missile (ICBM) such as Minuteman or Titan with ranges in excess of 3000 nautical miles. The ICBMs are fine for their purpose. No one, however, would consider firing one at a target that was less than 50 miles away. A need, therefore, exists for a comparatively short range surface-to-surface guided missile.

Tartar, Terrier, and Talos (3-Ts)

Unless you are assigned to a Basic Point Defense Missile System, you will be involved with one of the 3-Ts. The 3-Ts can be employed against air targets (surface-to-air), other ships (surface-to-surface), and shore installations (surface-to-shore). The manner in which the 3-Ts exploit their capabilities will be presented as we proceed through this training manual. For the present, we will say that the 3-Ts, as a family of missiles, are multipurpose weapons.

Basic Point Defense is primarily a surface-to-air system which employs the Sparrow missile.

Now that you are oriented in the world of guided missiles, prepare yourself for a more detailed look at this world.

SMS MISSILES

Operational missiles of the Navy's SURFACE MISSILE SYSTEMS are the TERRIER, TALOS, TARTAR, STANDARD MISSILE, and the SPARROW.

TARTAR Missiles

Today's operational missiles, deployed with the TARTAR Fleet, are the Improved TARTAR Missile RIM-24B (IT), Improved TARTAR Retrofit Missile RIM-24C (ITR), and the STANDARD Missile RIM-66A and B (MR), figure 2-1.

Tartar missile operation is based on roll stabilization, along with a dual thrust rocket motor, and employs homing guidance and proportional navigation. The warhead section contains a high-explosive continuous rod warhead.

TERRIER Missiles

Guided missiles now being employed on TERRIER ships are the RIM-2D, RIM-2E, RIM-2F, and RIM-67A, figure 2-2. The RIM-2D (BT) is a beam-riding missile equipped with either a nuclear or fragmentation type warhead. The RIM-2E (HT) and RIM-2F (HTR) are semi-active homing missiles, with passive home-on-jam capabilities when operating in an electronic countermeasure (ECM) environment. The RIM-67A (SM-1/ER) is an advanced semi-active homing missile using solid-state guidance electronic circuitry. The homing missiles are equipped with a high-explosive continuous-rod type warhead. Terrier missiles also have ARM (antiradiation missile) capabilites.

STANDARD MISSILE

Currently Improved TARTAR and Improved TARTAR Retrofit missiles are being replaced in the TARTAR Fleet by STANDARD Missiles (Type 1A), RIM-66A. STANDARD Missiles first reached the TARTAR fleet in 1968, and the Navy inventory will build steadily to replace TERRIER

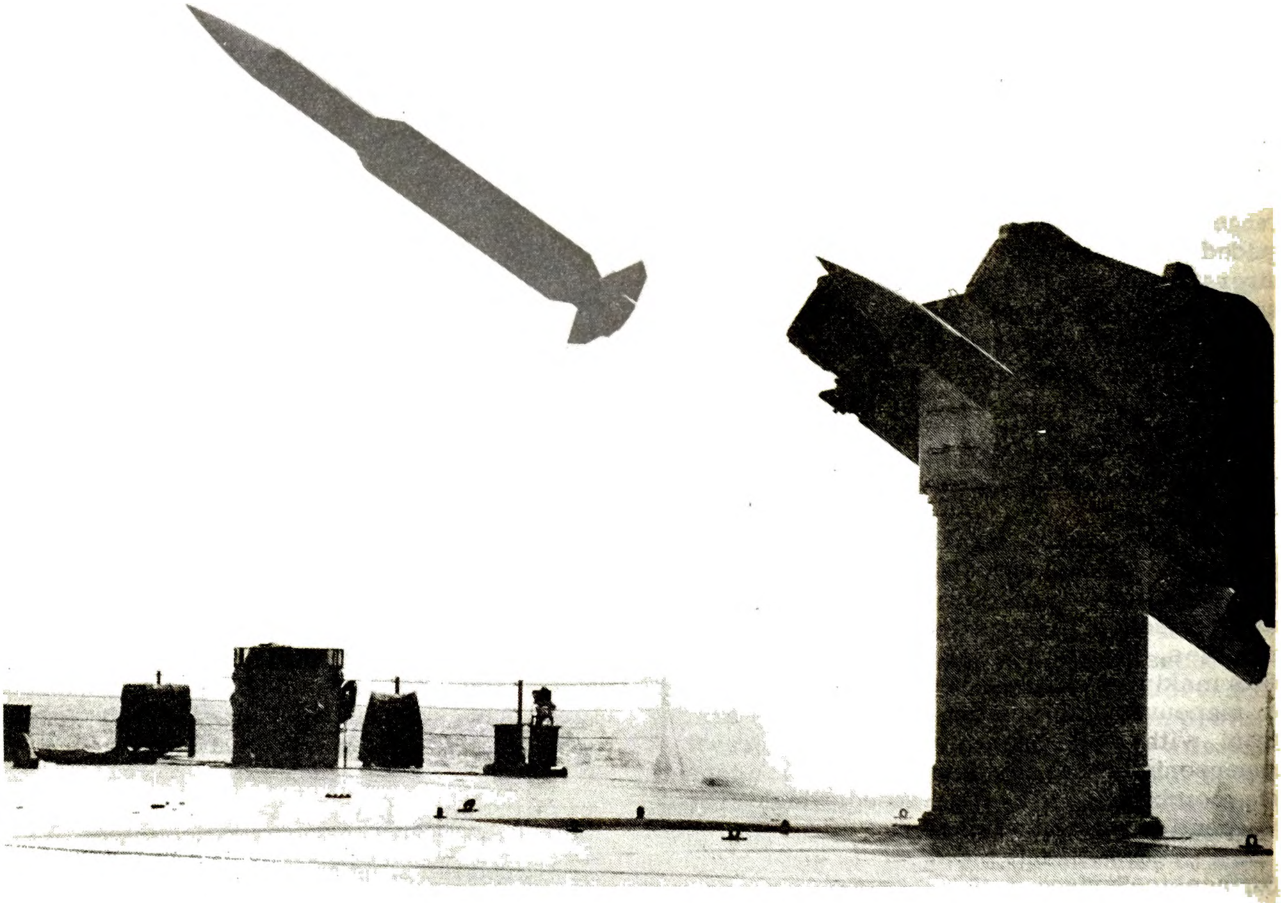

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Figure 2-1.—Tartar missile leaving launcher.

and TARTAR missiles as the first-line weapon in missile frigates and destroyers. The STANDARD Missile (SM-1), RIM-66B, started replacing the SM-1A in 1971 and will continue as the SM-1 becomes available.

One of the major objectives in the STANDARD Missile program was to develop an extended-range and a medium-range missile capable of being introduced into the TERRIER/TARTAR weapon systems with minimum need for compatibility changes; consequently, STANDARD missiles retain the same body diameters, finspans, and tailspans as the TERRIER RIM-2 series and the TARTAR RIM-24 series. The STANDARD missile is adaptable to either the TARTAR weapon system or the TERRIER weapon system with only a change in propulsion sections. STANDARD missiles also contain the ARM capability.

TALOS Missiles

The TALOS missile, figure 2-3, is a long-range, solid-fuel rocket-boosted, supersonic ramjet-propelled guided missile that can be used against single or massed groups of high-performance aircraft, or to bombard surface and shore targets. The capability of using either nuclear or high explosive warheads, along with reliable and accurate guidance and homing systems, make TALOS a versatile weapon. In addition to the capability of engaging aircraft targets, the TALOS missile can effectively engage patrol or escort and larger type surface ships at long range. The TALOS missile is also capable of destroying radiating surface or shore targets (ARM). TALOS comprises the main armament aboard six guided missile cruisers.

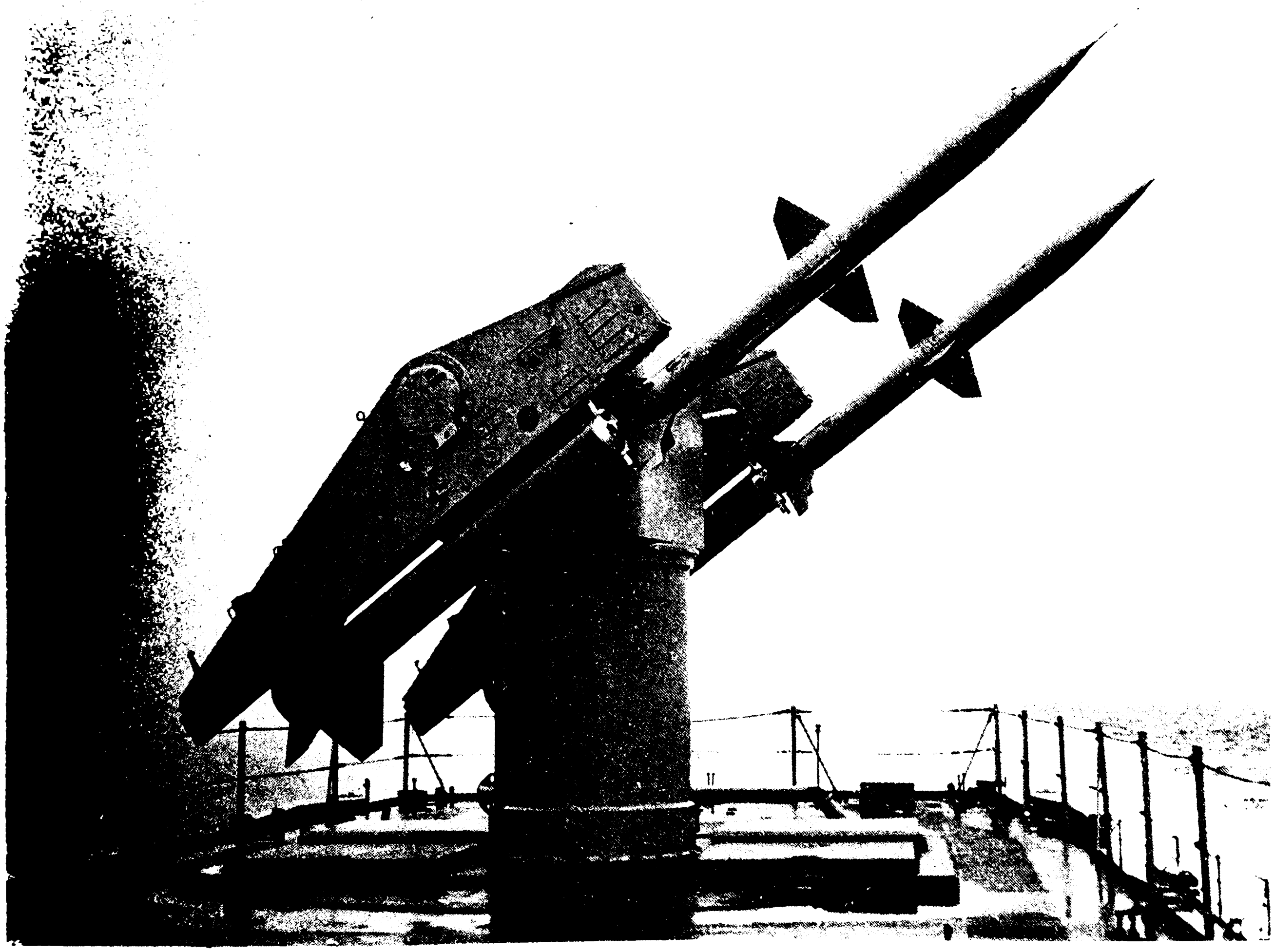

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Figure 2-2.—Terrier missiles and launcher.

SPARROW Missile

The guided missile for the Basic Point Defense (BPD) is the SPARROW III missile designated for air launch from fighter aircraft. For the basic point defense role, the missile has been modified by the substitution of special wings and tail fins which have less aerodynamic drag. The SPARROW III missile is a supersonic, boost-glide, semiactive homing missile. Tactical mission of the missile is to intercept and destroy enemy aircraft and guided missiles in point defense of individual surface vessels, figure 2-4. It also has limited use against surface targets. The basic point defense missile is designated as guided Missile AIM-7 (Series) SPARROW III.

MISSILE DESIGNATION

Components of Navy missiles are assigned mark (Mk) and modification (Mod) numbers. Missiles having two-stage propulsion systems (separate boosters), for instance the TERRIER, TALOS, and STANDARD (ER) MISSILE have mark and modification numbers assigned to the separate propulsion subsystem but one designation for the complete missile, figure 2-5.

Reaction-propelled missiles are categorized according to the environment from which the missile is launched, the type of mission the missile is intended to perform, the missile type,

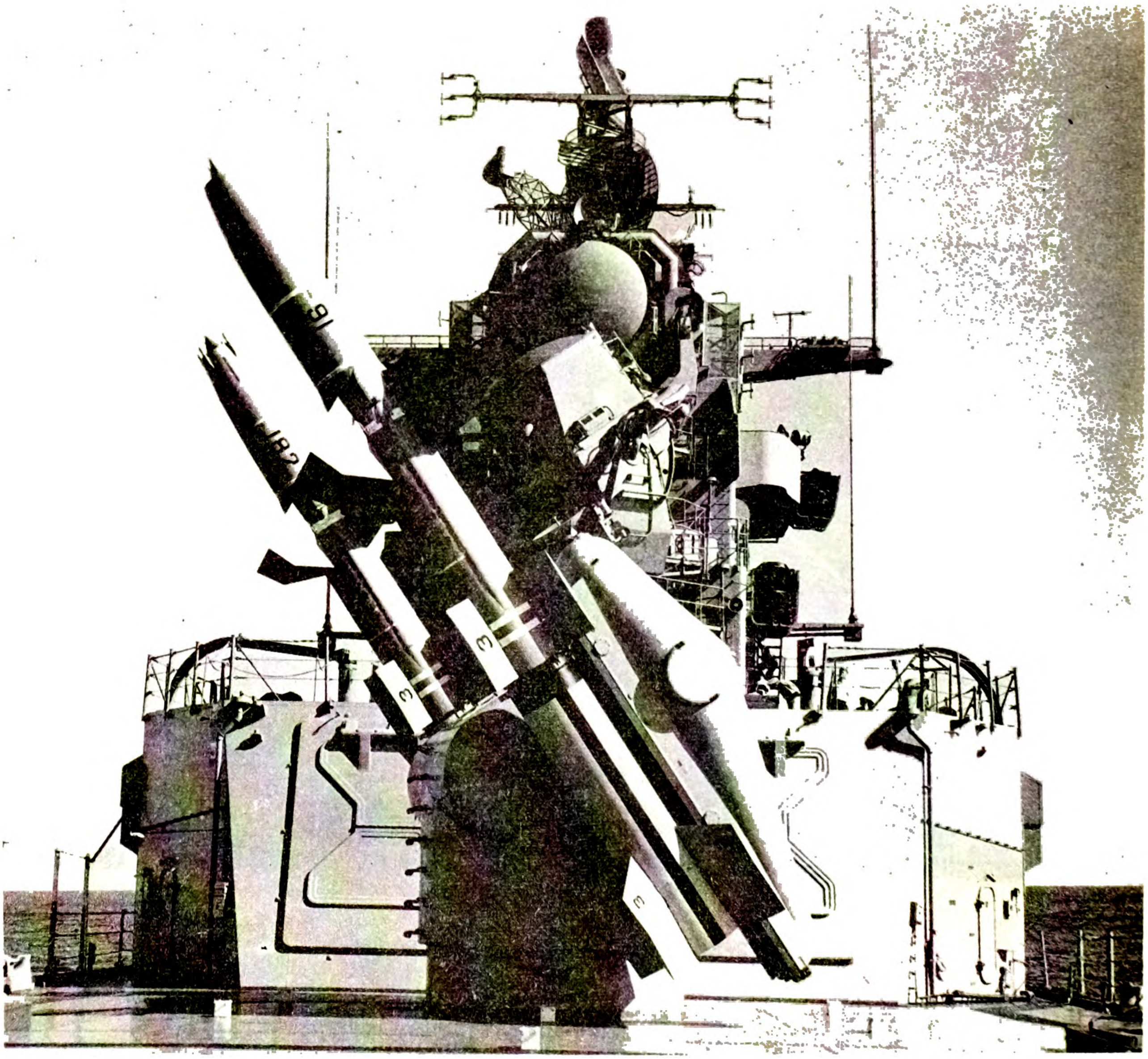

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Figure 2-3.—Talos missiles on launcher.

the design number of the missile, and the series number of the missile. For example, examining table 2-1, it can be determined that the RIM-2E is a ship launched guided missile designed to intercept air targets. This missile has been assigned the design number 2 and the E indicates that it is the fifth modification to the design. RIM-2E is the designation of the TERRIER HT-3 missile.

MISSILE SUBSYSTEMS

You have learned that all guided missiles are made up of 5 main subsystems in order to perform their mission, figure 2-6. The missile must have a body or basic structure; it must be propelled; it must be guided; and it must carry a payload. The principle structure of the missile, which houses the other subsystems, is called the STRUCTURE, also commonly known as

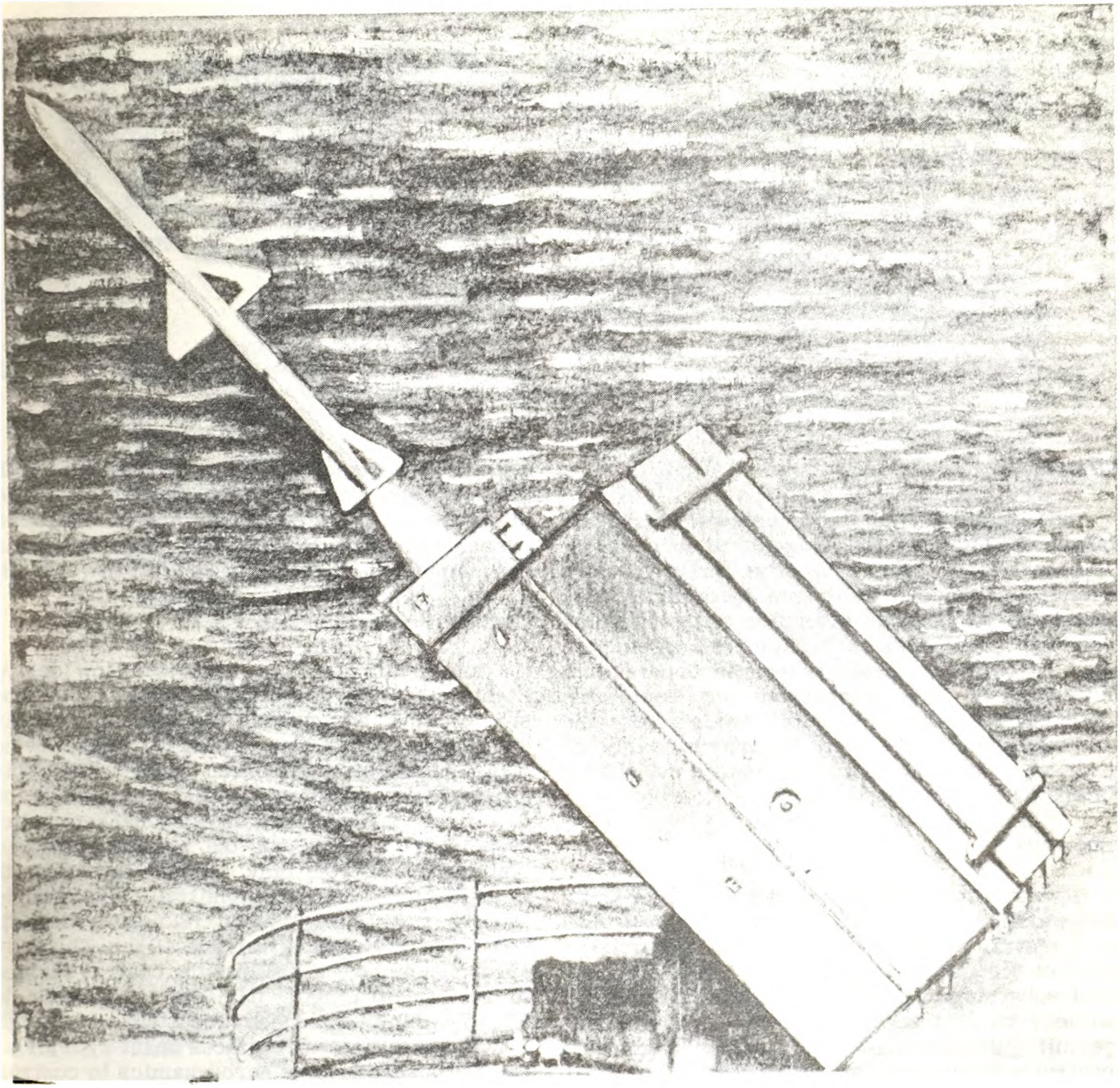

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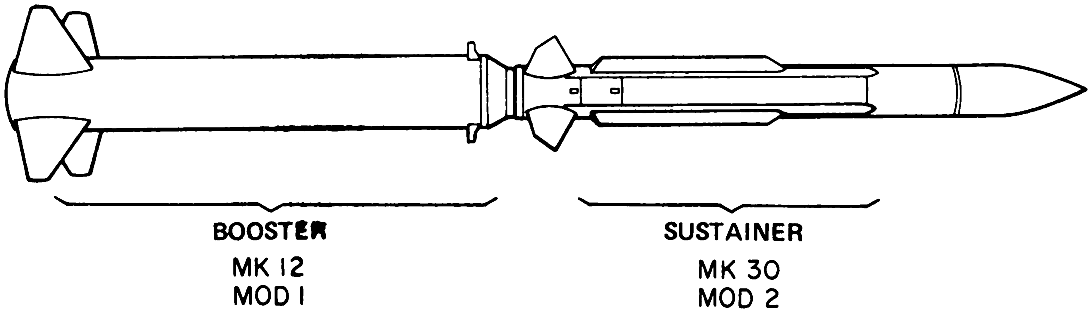
Figure 2-4.—Sparrow III missile, basic point defense.

the airframe. The subsystem which moves or propels the structure is the PROPULSION SYSTEM, or power plant. The subsystem which makes the missile a true guided missile is the GUIDANCE AND CONTROL section. Further, if the missile is to perform a useful military mission, it must contain a payload consisting of a WARHEAD AND FUZES.

Various types of these subsystems are discussed here to serve as a basis for future study, and many of the terms applied to guided missiles are introduced.



name: STANDARD MISSILE
designation: RIM-67A (ER)

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Figure 2-5.—Missile component designation.

Warheads

The warhead effectively destroys a target or target complex by converting stored chemical or nuclear energy into destructive force; by producing high velocity fragments; by creating blast effects of tremendous potential; or by releasing chemical, biological or radiological agents into the atmosphere. The warhead incorporates a fuze element that recognizes or senses the optimum time for detonation, and a safety and arming element (S & A) to prevent early or premature detonation and to combat the effects of enemy countermeasures.

Structure

The structure contains supports, and protects the warhead and other subsystems during launch and travel to the target. It must support and protect the propulsion, guidance, and flight control subsystems; must be aerodynamically sound while providing external control surfaces that permit guidance signals to initiate flight path control action; and must be designed to the proper strength-to-weight ratio.

Propulsion

The propulsion subsystem provides the power or energy necessary to propel or move the missile to the target.

Increased propulsion may be achieved by the use of more than one propulsion unit. For example, a booster rocket may be employed to accelerate a missile to a desired flight speed prior to the operation of the sustainer engine. Once it has expended its propelling force, the booster separates from the missile, as shown in figure 2-7. The sustainer engine then takes over and provides the propelling force necessary to maintain the design speed of the missile.

Control

Guided missiles are made to follow desired flight paths by both reflexive stabilizing methods and active error sensing methods. In reflexive stabilizing, the primary setting of control devices takes place before launch where initial missile attitude and interior ballistic considerations determine the required launch characteristics. Once the missile leaves the launcher, however, stabilization is the only control that keeps the missile on the desired flight trajectory. The reflective stabilizing method is used during the boost phase of guided missile flight. The active error sensing method allows the control surfaces to respond to missile path deviation error detected within the guidance subsystem during flight.

Moveable control surfaces react with air according to the laws of aerodynamics to control a missile in flight. The control surfaces may be located in any position, depending on the dynamic and structural requirements. Examples of control surface designs and locations are shown in figure 2-8.

Guidance

A guidance subsystem senses the missile position with respect to its target and initiates action to correct any deviation from the flight path required to intercept the target. A guidance

Table 2-1.—Missile categories

LAUNCH ENVIRONMENT SYMBOLS

Letter	Title	Description
A	Air	Air launched.
B	Multiple	Capable of being launched from more than one environment.
C	Coffin	Stored horizontally or at less than a 45 degree angle in a protective enclosure (regardless of structural strength) and launched from the ground.
H	Silo Stored	Vertically stored below ground level and launched from the ground.
L	Silo Launched	Vertically stored and launched from below ground level.
M	Mobile	Launched from a ground vehicle or movable platform.
P	Soft Pad	Partially or nonprotected in storage and launched from the ground.
R	Ship	Launched from a surface vessel, such as ship, barge, etc.
U	Underwater	Launched from a submarine or other underwater device.

MISSION SYMBOLS

D	Decoy	Vehicles designed or modified to confuse, deceive, or divert enemy defenses by simulating an attack vehicle.
E	Special Electronic	Vehicles designed or modified with electronic equipment for communications, countermeasures, electronic radiation sounding, or other electronic recording or relay missions.
G	Surface Attack	Vehicles designed to destroy land or sea targets.
I	Intercept-Aerial	Vehicles designed to intercept aerial targets, defensive or offensive roles.
Q	Drone	Vehicles designed for target, reconnaissance, or surveillance purposes.
T	Training	Vehicles designed or permanently modified for training purposes.
U	Underwater Attack	Vehicles designed to destroy enemy submarines or other underwater targets or to detonate underwater.
W	Weather	Vehicles designed to observe, record, or relay meteorological data.

VEHICLE TYPE SYMBOLS

M	Guided Missile	Unmanned, self-propelled vehicles designed to move in a trajectory or flight path all or partially above the earth's surface and whose trajectory or course, while the vehicle is in motion, can be controlled remotely or by homing systems, or by inertial and/or programmed guidance from within. This term does not include space vehicles, space boosters, or naval torpedoes, but does include target and reconnaissance drones.
N	Probe	Non-orbital instrumented vehicles not involved in space missions that are used to penetrate the aerospace environment and report information.
R	Rocket	Self-propelled vehicles without installed or remote control guidance mechanisms, whose trajectory cannot be altered after launch. Rocket systems designed for line of sight are not included.

The military designation of the ASROC missile is RUR-5A since it is a ship launched rocket designed to destroy enemy submarines. It is the first (A) of its assigned design number (5).

If necessary, to denote a special status, one of the following letters is affixed before the military designation.

STATUS PREFIX SYMBOLS

J	Special Test (Temporary)	Vehicles especially configured simply to accommodate test.
N	Special Test (Permanent)	Vehicles so modified they will not be returned to original use.
X	Experimental	Vehicles under development.
Y	Prototype	Preproduction vehicles for test.
Z	Planning	Vehicles in planning stage.

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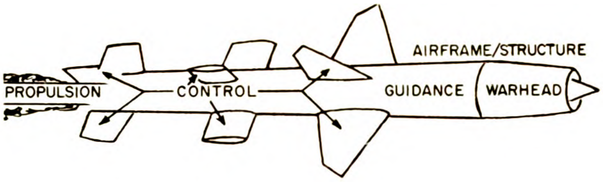

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Figure 2-6.—Typical arrangement of missile components.

subsystem may alter the course during flight in response to target data or exterior inputs such as commands or radar beam directional shifts. There are many types of guidance subsystems in use, classified by means of the method used to sense position (see fig. 2-9). Two methods of guidance used with the surface missile system (SMS) are beam rider and homing.

BEAM RIDER.—The beam rider missiles, Terrier and Talos, are directed along an energy line between the beam energy source and the target. Fire control radar equipment on the ship tracks a target and sends the information to the missile. The guidance and control system within the missile then interprets this data and formulates its own steering commands.

HOMING.—In semiactive homing, used by the Terrier, Talos, Tartar and Sparrow III missiles, the target is illuminated by a tracking radar at the launching ship. The missiles are equipped with receivers and, by means of the reflected radar energy from the target, formulate their own correction signals on the basis of the tracking information.

STRUCTURE

The term STRUCTURE, sometimes called the AIRFRAME, has the same meaning for guided missiles as it has for the airplane. It serves as a vehicle to carry all the other parts of the missile, and it provides the aerodynamic characteristics required for successful flight. For the purpose of this text, the control surfaces (wings or tails) are considered as part of the AIRFRAME-STRUCTURE.

Since the guided missile is essentially a one-shot weapon, its structure can be simpler than that of the airplane; i.e., it needs no landing gear or cockpit. Missile bodies are designed so that inner components are readily accessible for testing, removal and repair. The major components are mounted to form independent units or packages.

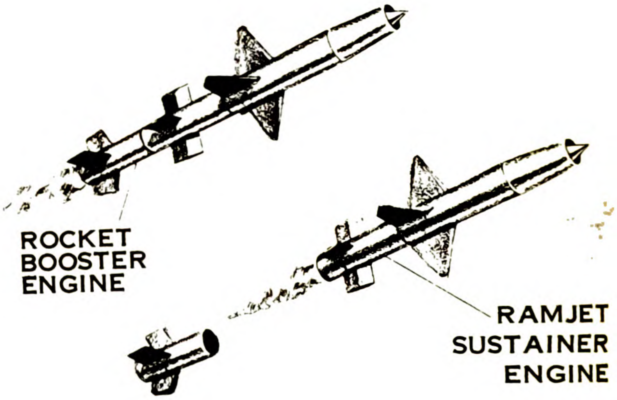

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Figure 2-7.—Booster rocket employment.

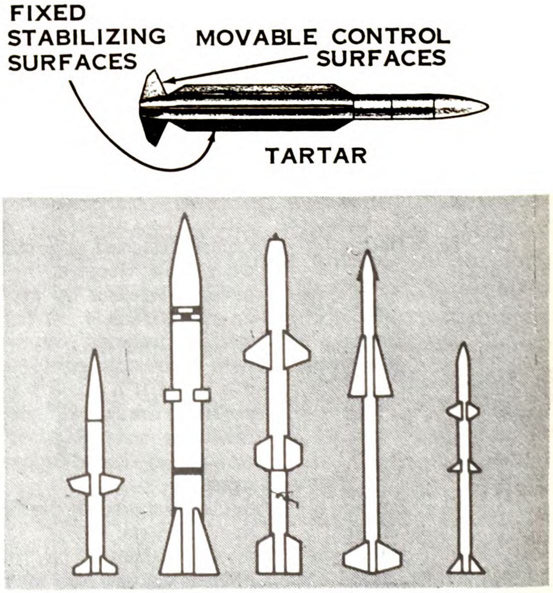

Figure 2-8.—Control surface designs and locations.

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Construction

Missiles, for the most part, are made up of several sections (fig. 2-10). Each section is a cylindrical shell machined from metal tubing, and contains one of the essential units or components of the missile, such as the propulsion system, the electronic control equipment, the warhead, or the fuze assembly.

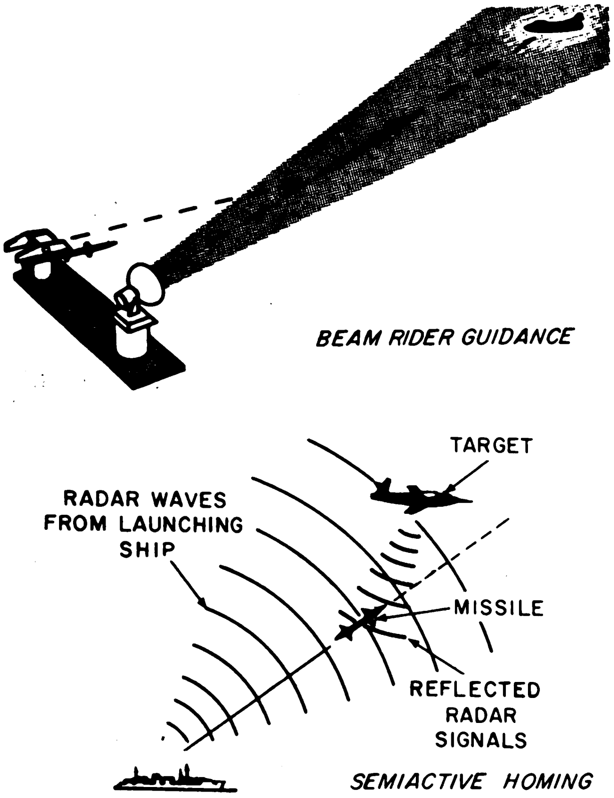

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Figure 2-9.—Methods of guidance.

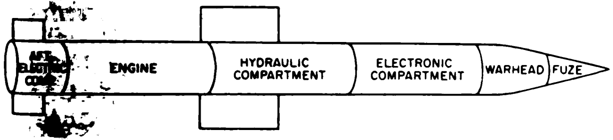

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Figure 2-10.—Sectionalization of a missile.

Sectionalized construction has the advantage of strength with simplicity, and also provides ease in replacement and repair of the components, since the shells are removable as separate units. The sections are joined by various types of connections designed for simplicity of operation. Access ports are sometimes provided in the shells, through which adjustments can be made prior to launching. Covers and access doors are sealed to prevent moisture and dirt from entering the missile.

The fuselages of many of the larger guided missiles, such as Talos, resemble those of modern aircraft in construction, being based on the SEMIMONOCOQUE structure which is widely used in conventional airframes. The semimonocoque fuselage (the word ''monocoque'' means ''one shell'') consists of a metal skin or shell which is internally braced. The strength of the body is provided mainly by the shell, which is reinforced by inner bulkheads, called FRAMES, and longitudinal braces, called STRINGERS.

Basically, the missile is designed to carry the warhead to the target. The size and weight of the warhead must be accommodated by the missile structure. The missile must be as light and compact as possible, yet strong enough to carry the warhead (and other components), and withstand the forces to which it will be subjected, such as gravity, air pressure, winds, heat, stresses of acceleration and deceleration, and other forces. Every pound of weight saved in the missile structure reduces the fuel requirement. The weight and balance relationships must be given careful consideration. The initial location of the center of gravity is of extreme importance. The center of gravity can change during missile flight because of the burning of the propellant, and separation of the booster after burnout. These factors and others must be carefully included in the calculations of the missile designers to produce a structure that will perform as expected.

In most missiles the main body is a slender, cylindrical structure. Several types of nose sections are employed (fig. 2-11). If the weapon is intended for speeds exceeding that of sound, the forward section usually has a pointed-arch profile in which the sides taper in lines called ''ogive'' curves. In missiles which fly at lesser speeds, the nose is frequently less sharp or is even blunt. In some, the forward end is covered by a rounded radome (the housing for a radar antenna); in others, the nose section contains the opening which forms one end of the duct required for the jet power system.

The nose shape is determined by other requirements. The Terrier nose (not all mods) is long and slender, because that shape has been found highly efficient at supersonic speeds.

The nose of Talos contains the air intake for the ramjet engine. Ramjet engines will be covered later in this chapter.

Talos is, in effect, a double-walled tube. Its central part is taken up by the ramjet engine. All of its other components—warhead, fuel tanks, guidance and control systems—are crowded within the space between the inner and outer walls. (In one model, one of these components is carried

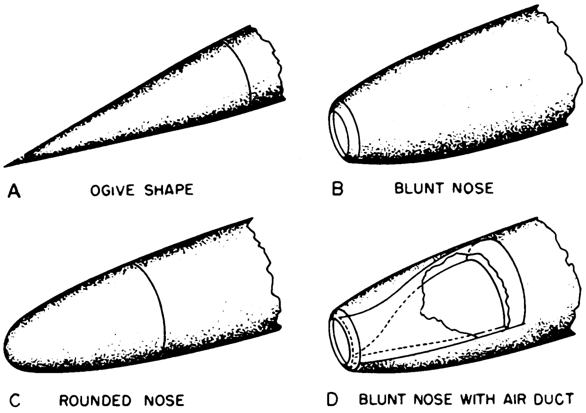

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Figure 2-11.—Missile noses.

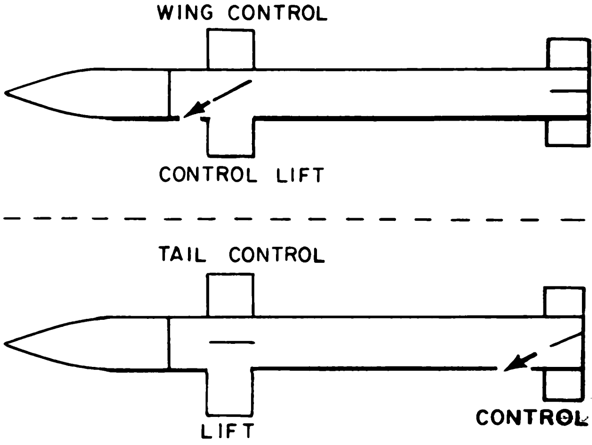

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Figure 2-12.—Missile airframe design with respect to control surface locations.

inside the central diffuser in the nose.) The middle part of Terrier is taken up by a chamber filled with solid rocket propellant. The warhead, fuze, and the major part of the guidance and control systems, are located forward of the fuel chamber. But a part of the guidance and control system is located in the double-walled cylinder that surrounds the exhaust duct at the after end of the missile. Electric cables and pneumatic lines to maintain communication between the two parts of the guidance system pass through covered channels along the outside of the missile.

Typical airframes contain a main body which terminates in a flat base. When the contour is slightly streamlined at the rear, the missile is said to be "boattailed." Attached to the body are one or more sets of airfoils, which provide lift in some cases, and which control the flight path and increase the stability. The basic types of design which are employed in missile airframes are distinguished principally by the location of the control surfaces with respect to the missile body. These types are the WING-CONTROL and TAIL-CONTROL designs, (fig. 2-12).

In the wing-control design, the control surfaces are mounted at or near the center of gravity. In the tail-control configuration, the control surfaces are placed at the rear of the airframe.

Most modern missiles have wings and fins. Tartar and Terrier have permanent dorsal fins and folding tail-control surfaces (fins). Talos has removable wings and fins. The wings and/or fins are folded or removed for stowage including the Terrier booster fins which are removable. The size, shape and location of the wings and fins have undergone extensive changes for use at supersonic speeds. Newest mods of Tartar (fig. 2-13) and Terrier have dorsal fins, which are used to provide missile stability and some lift during missile flight. Pivoting of the tail fins provides missile flight path control with this type of configuration. More will be said about missile control surfaces in forthcoming sections of this chapter.

Typical Configurations

Terrier and Talos are typical of present day airframes (fig. 2-14). In general, the air frame is a long, slender cylinder with fixed fins providing stability. Talos control is by wings located at the midsection of the missile (disregard the booster), Terrier control is by means of tail fins. Control is accomplished by pivoting one or more pairs of either the wings for Talos or the tail fins for Terrier.

At this point, let us digress for a moment and take up the subject of aerodynamics, which is basic not only to the understanding of the physical features of guided missiles but to understanding guidance and flight control as well.

Missile Aerodynamics

Guided missiles travel through and are affected by the earth's atmosphere. The atmosphere is the gaseous envelope surrounding the

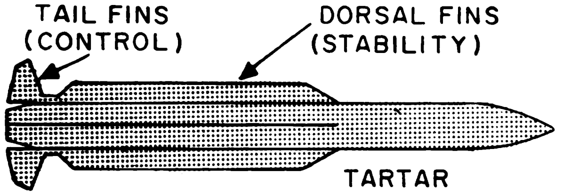

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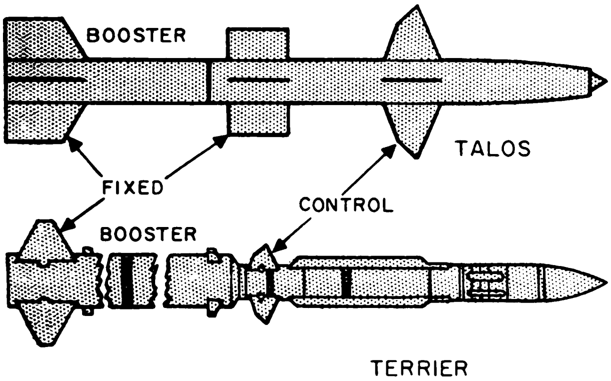
Figure 2-13.—Tartar configuration.



144.2.2
144.2.3
Figure 2-14.—Talos and Terrier configurations.

earth to a height of roughly 250 miles. One of the most important characteristics of the atmosphere is the change in air density with a change in altitude. (Density is a measure of the weight per unit volume of a substance.) Because of the significant decrease in air density with altitude, a missile flying at 35,000 feet encounters less air resistance to its passage—that is, less DRAG—than does a missile flying close to sea level.

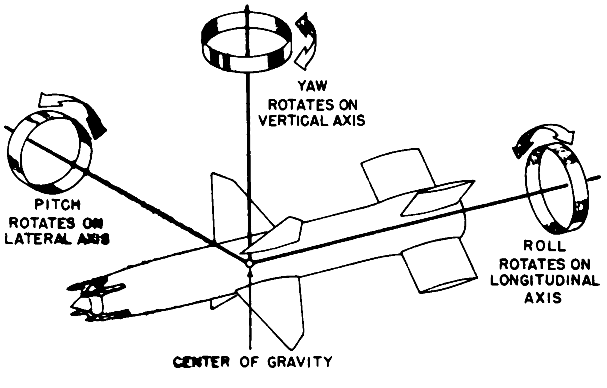
BASIC FLIGHT PRINCIPLES.—Aerodynamics is the science that deals with the motion of air and other gases, and with the forces acting on bodies moving through these gases. The principles of aerodynamics which underlie the operation of most aircraft also apply to missiles, at least in some phases of flight. Before discussing high speed missile flight, let us consider the motions and forces that are common to both guided missiles and aircraft.

Basic Motions.—Like any moving body, the guided missile executes two basic kinds of motions: ROTATION and TRANSLATION. In pure rotation all parts of the body pivot about the center of gravity, describing concentric circles around it. In movements of translation, or linear motions, the center of gravity of the body moves along a line, and all the separate parts follow lines parallel to the path of the center of gravity. Any possible motion of the body is composed of one or the other of these motions, or is a combination of the two.

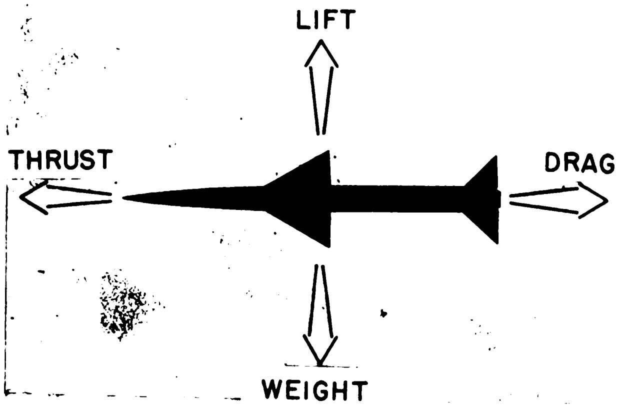
Missiles, like other aircraft, are free to move in three dimensions. To describe their motions we use a reference system containing three reference lines, or axes. The missile axes, illustrated in figure 2-15, are three mutually perpendicular lines which intersect at the center of gravity of the missile.

Three kinds of rotary movements can be made by the missile: PITCH, ROLL, and YAW. Pitch, or turning up or down, is rotation about the lateral axis, the reference line in the horizontal plane, perpendicular to the line of flight. The missile rolls, or twists, about the longitudinal axis, the reference line running through the nose and tail. It yaws, or turns to the right or left, about the vertical axis. Rotary motions about all three of these axes are controlled by devices within the missile. Hereafter, these axes will be referred to as the pitch axis, the roll axis, and the yaw axis.

Aerodynamic Forces.—The principle forces acting on a missile in level flight are THRUST, DRAG, WEIGHT, and LIFT. Like any force, each of these is a vector quantity which has magnitude (length) and direction. These forces are illustrated in figure 2-16.



33.22
Figure 2-15.—Missile axes: pitch, roll, and yaw.

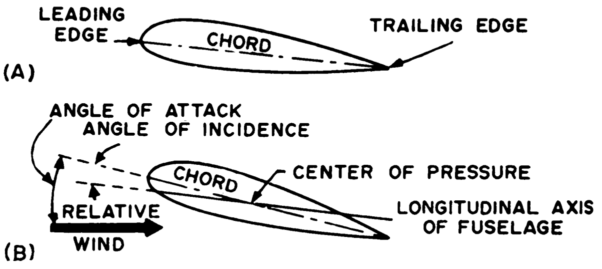


33.23
Figure 2-16.—Forces acting on a moving missile.

Thrust is directed along the longitudinal axis of the missile and is the force which propels it forward at speeds sufficient to sustain flight. Drag is the resistance offered by the air to the passage of the missile body through it, and is directed rearward. The weight of the missile is the force of gravity on the body, and is directed downward toward the center of the earth. Opposed to the force of gravity is the lift and upward force which supports the body. Lift is directed perpendicular to the direction of drag.

Lift is produced by means of pressure differences. The primary factor contributing to lift is that the air pressure on the upper surface of an airfoil (wing) must be less than the pressure on the underside. The amount of lifting force provided is dependent to a large extent on the shape of the wing. Additional factors which determine the amount of lift are the wing area, the angle at which the wing surface is inclined to the airstream, and the density and speed of the air passing around it. The airfoil that gives the greatest lift with the least drag in subsonic (less than the speed of sound) flight has a curved shape (camber) similar to the one illustrated in figure 2-17.

Some of the standard terms applied to airfoils are included in the sketch (fig. 2-17). The foremost edge of the wing is called the LEADING EDGE, and that at the rear the TRAILING EDGE (fig. 2-17A). A straight line between the leading and trailing edges is called the CHORD. The large arrow (fig. 2-17B) indicates the RELATIVE WIND, the direction of the airflow with reference to the moving airfoil. The ANGLE OF ATTACK is the angle between the chord and the directions of the relative wind.



33.24
Figure 2-17.—Wing cross section.

The relative wind strikes the tilted surface, and as the air flows around the wing different amounts of lifting force are exerted on various points on the airfoil. The sum (resultant) of all these forces is equivalent to a single force acting at a single point and in a particular direction. This point is called the CENTER OF PRESSURE. From it lift can be considered to be directed perpendicular to the direction of the relative wind.

The dynamic or impact force of the wind against the lower surface of the airfoil contributes to lift, but the major portion of the lifting force is obtained from the differential pressure of the air above and below the airfoil. The angle of attack causes the air flowing over the wing to travel a greater distance than the air which flows under the wing. The air flowing over the wing will increase its speed, and thus cause a reduction in air pressure above the wing. The greater the distance the air must travel, the faster it will travel and the lower its pressure will become. The air pressure is therefore higher under the wing and the pressure difference is a force acting on the wing in the direction of the lower pressure. The magnitude of the lifting force is proportional to the pressure difference.

CONTROL

Aerodynamic control is the connecting link between the guidance system and the missile flight path. Effective control of the flight path requires smooth and exact operation of the missile control surfaces. The control surfaces must have the best possible design configuration for the intended speed of the missile. They must be moved with enough force to produce the necessary change of direction. Methods must be found for balancing the various controls, and for changing them to meet the variations of lift and drag at different Mach speeds so as to maintain missile stability.

Stability and Lift

So far we have discussed the principles of producing lift by the use of cambered wings (curved wing). Cambered wings are still used on conventional aircraft but are not used on most present day guided missiles. Most operational missiles use streamlined fins to provide stability and some lift.

The Navy's SMS missiles are designed to travel at supersonic speeds. Lift is achieved almost entirely by the thrust of the main propulsion system. The missile fins must present streamlined airflow surfaces to reduce air turbulence, and therefore are not cambered like the conventional wing. The lift that a fin does contribute is based on a slightly different principle. At subsonic speeds a positive angle of attack will result in impact pressure on the lower fin surface which will produce lift just as with the conventional wing. At supersonic speeds, the formation of EXPANSION WAVES and oblique shock waves also contributes to lift. Figure 2-18 shows the upper surface of a supersonic fin. Due to the fin shape, the air is speeded up through a series of expansion waves. This results in a low pressure area above the fin. Figure 2-19 shows the fin cross section. Beneath the fin, the force of the airstream (dynamic pressure) and the formation of oblique shock waves result in a high pressure area. The differences in pressure above and below the fin produce lift.

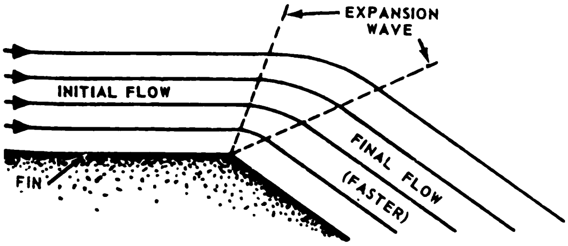


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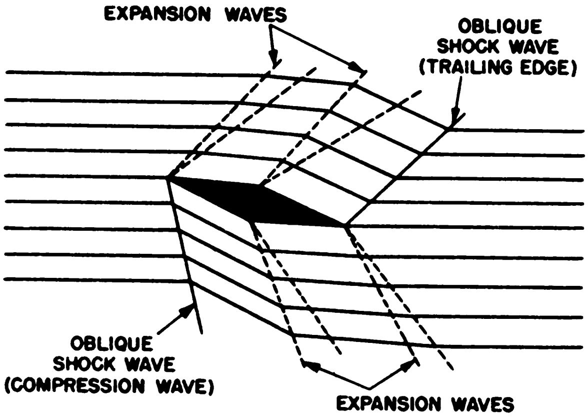
Figure 2-18.—Expansion wave.


EXPANSION WAVES
OBLIQUE SHOCK WAVE (TRAILING EDGE)
OBLIQUE SHOCK WAVE (COMPRESSION WAVE)
EXPANSION WAVES

33.30
Figure 2-19.—Airflow about supersonic fin.

FIN DESIGNS.—Supersonic fins are symmetrical in thickness cross section and have a small thickness ratio—the ratio of the maximum thickness to the chord length. The DOUBLE WEDGE, shown in figure 2-20A, has the least drag for a given thickness ratio, but in certain applications it is inferior because it lacks strength. The MODIFIED DOUBLE WEDGE has relatively low drag (although its drag is usually higher than a double wedge of the same thickness ratio) and is stronger than the double wedge. The BIOCONVEX, also shown in the figure, has about one-third more drag than a double wedge of the same thickness ratio. It is the strongest of the three but is difficult to manufacture.

The planform of the fins—the outline when viewed from above—is usually either of the DELTA-MODIFIED DELTA (raked tip) or RECTANGULAR types shown in figure 2-20B. These shapes considerably reduce unwanted shock wave effects. The combination of a raked tip and cathedral droop (fig. 2-20C) of the wings permits better control as the swept-back wings delay air compressibility.

ARRANGEMENT OF FINS.—Fins are mounted on the airframe/structure in several arrangements, some of which are shown in figure 2-21. The cruciform is the most popular wing and tail arrangement and the INLINE cruciform arrangement is predominant in SMS Missiles.

External Control Surfaces

The simplest control surfaces are fixed fins. The flight of an arrow is an example of stability

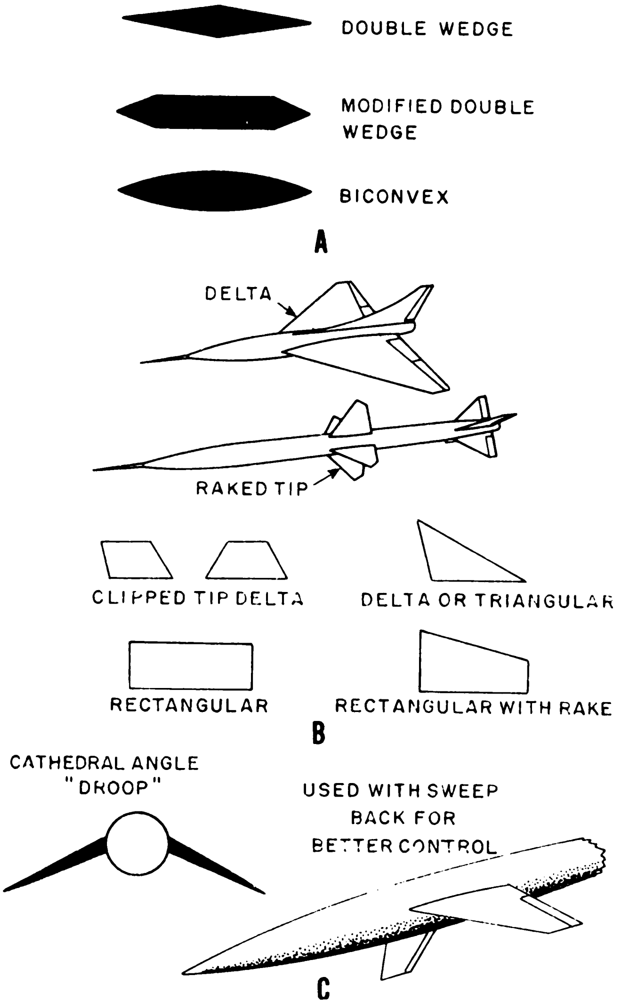


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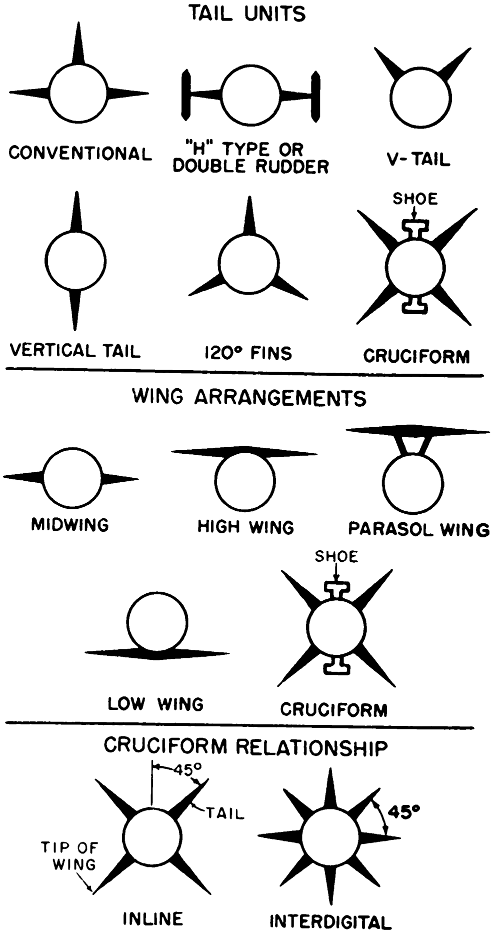
Figure 2-20.—High speed configuration characteristics.



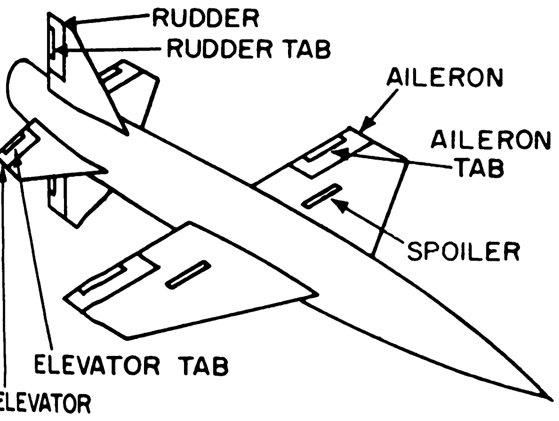
33.35
Figure 2-21.—Arrangement of control surfaces.

provided by fixed fins. The feathered fins on an arrow present streamlined airflow surfaces which ensure accurate flight. As long as the arrow is flying true its fins present their slim longitudinal axes to the airflow. If the arrow attempts to tumble or to curve left or right, it must do so against the resistance of the lateral axis of the fins to the airflow. The lateral axis of the fin has a large area that provides a proportionally large amount of resistance to any deviation from normal flight.

Guided missiles are also provided with movable control surfaces, since stationary fins cannot provide the precise control needed to keep the missile on a desired course. Before discussing the controls on today's modern missiles, however, let's look at the control devices on the conventional type missile (fig. 2-22).

Conventional Control

Movable control surfaces can be divided into two types: primary and secondary. The primary controls include ailerons, elevators, and rudders (fig. 2-22). Secondary control surfaces include tabs and spoilers. Primary control devices are responsible for maintaining missiles along desired trajectories. If no unstabilizing conditions were present, primary control could function satisfactorily. A missile can be controlled more accurately and more efficiently, however, by the



33.39

Figure 2-22.—Control devices on conventional type missiles.

use of secondary controls, in various combinations, working in conjunction with primary controls.

Ailerons, elevators, and rudders are attached to fixed wings and tails as in a conventional aircraft.

In figure 2-22, ailerons are attached to the trailing edges of the wings. When one aileron is lowered, the other is raised. Movement of the ailerons changes the wing camber and brings about roll control. The wing with the raised aileron moves down and the other wing moves up.

Elevators attached to the horizontal tail stabilizers may be used for pitch control. The elevators are raised or lowered together.

Rudders attached to the vertical stabilizers (fig. 2-22) may be used for yaw control.

If the rudder moves to the right the tail moves to the left, and the missile yaws to the right.

Tabs are hinged to primary control surfaces, and the force exerted by these devices is directed to act against a primary control and not the missile itself. For example, consider a tab (fig. 2-22) on an elevator. If the tab moves upward, the deflected air will exert a downward force on the elevator. The elevator will then move down. Note that it is still the elevator, not the tab, that directly controls the missile. A fixed tab is preset for a given condition of stability; a trim tab is controllable and its setting can be varied over a wide range of conditions. A booster tab is used to assist in applying force to move control surface of large areas.

A spoiler can be any of several devices—for example, a hinged flap on the upper surface of the wing. Suppose that a gust of air causes the left wing to lose lift. The spoiler on the right wing can be raised to "spoil" the smooth flow of air over it, and thus decrease its lift to equal that of the other wing.

Dual Purpose Control

The primary and secondary control devices discussed above are used on older type missiles. For high-speed missiles, new control surface designs have been developed. Examples of such surfaces are elevons, rollerons, ruddervators, and ailevators. As the names indicate, these are multipurpose control devices. For example, an elevon replaces an elevator and an aileron, allowing control of pitch and yaw by a single control mechanism.

If operated together, they serve as elevators; if operated differentially, they serve as ailerons. If the missile tail surfaces were inclined upward, to form a V with the missile axis, controls on the trailing edges of these surfaces could be used as ruddervators. By suitable combinations of movements, they could control the missile in both pitch and yaw.

Cruciform Control (3-T's)

WING CONTROL.—Wing control is accomplished by wing incidence movements. As a rule, the surfaces are fixed and provide stabilization only. Wing control, through a variable and controllable angle of incidence of the wings, is possible because of the relative small size of the wing.

The design velocity of the missile has to be high to enable the small surface area of the wing to control the missile. In the case of a beam rider, the wing movement is proportional to the angular and linear displacement of the missile from the axis of the guidance beam. With a homer, it would depend on the amount of missile maneuver required to maintain a collision course with a target.

The wing movements are independently variable within their limits, and a combination of direction changes and roll corrections may be occurring at any one time.

All wing incidence movements are measured from a zero degree reference line at the wing root-to-missile skin junction, which is parallel to the missile centerline. Movements in which the leading edge of the wing is above the zero reference line are considered positive incidence, while movements in which the leading edge of the wing is below the zero degree reference line are considered negative incidence.

Guidance Control.—Guidance control is accomplished by the opposite wings (in the same plane) acting together. (In figure 2-23, wings are numbered the same as the tail fins.)

Wings 1 and 3 operate in the "A" plane; wings 2 and 4 operate in the "B" plane (fig. 2-23). Thus, if wings 1 and 3 in the "A" plane have a positive angle of incidence, they steer the missile up and to the left. A negative incidence of wings 1 and 3 would steer the missile down and to the right. In general, if a signal is given for the missile to climb in a straight ahead position, all four wings (wings in both planes) will increase the angle of incidence, as shown in figure 2-24. A dive signal will result in a negative angle of incidence, as shown in figure 2-25.

To obtain a level right turn, wings 2 and 4 increase in angle of incidence, and wings 1 and 3 decrease in angle of incidence (fig. 2-26). To effect a left turn, wings 1 and 3 increase in angle of incidence while 2 and 4 decrease in angle of incidence. The missile does not bank in a turn. (Remember that the wings are located at or near the center of gravity.)

Roll Stabilization.—Roll stabilization is accomplished by differential movement of wings in the same plane. Thus, in the "A" plane, to accomplish a roll correction (fig. 2-27), wing 3 has a positive angle of incidence, while wing 1 has a negative angle of incidence.

TAIL CONTROL.—If you understand the effects of wing control, you should have no problem in analyzing tail control. A word of caution! Consider the location of the control surface. In a tail controlled missile, deflection of the control surfaces produces drag in the form of an aerodynamic force perpendicular to the plane of each control surface, a component of which is perpendicular to the missile longitudinal axis. This component force causes rotation of the missile longitudinal axis about the center of gravity.

Because the control surfaces are located some distance from the center of gravity, they have a large mechanical advantage resulting from the length of the lever arm provided.

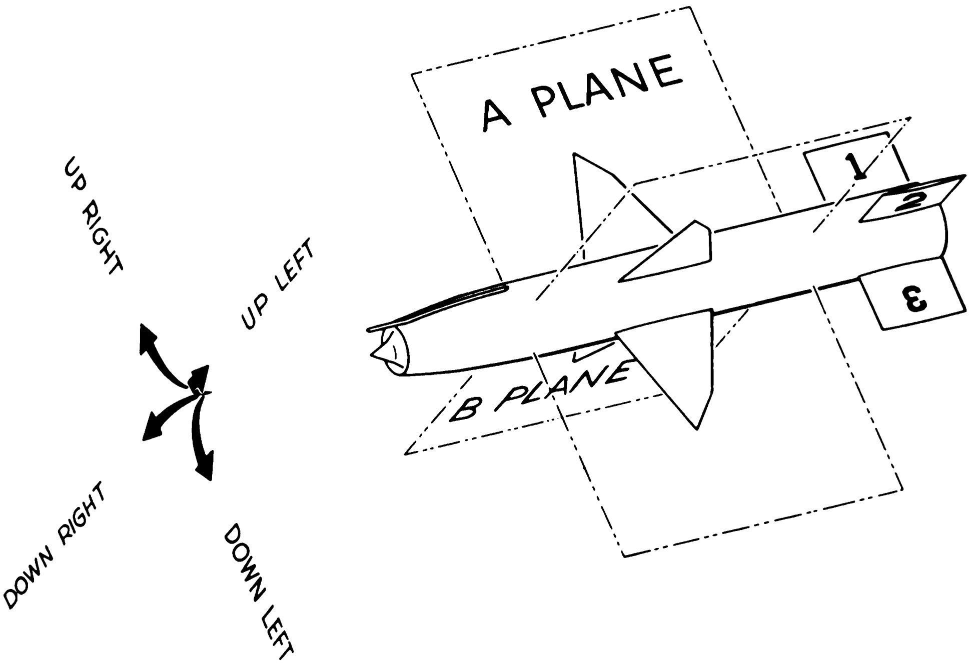


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Figure 2-23.—Planes of maneuver.

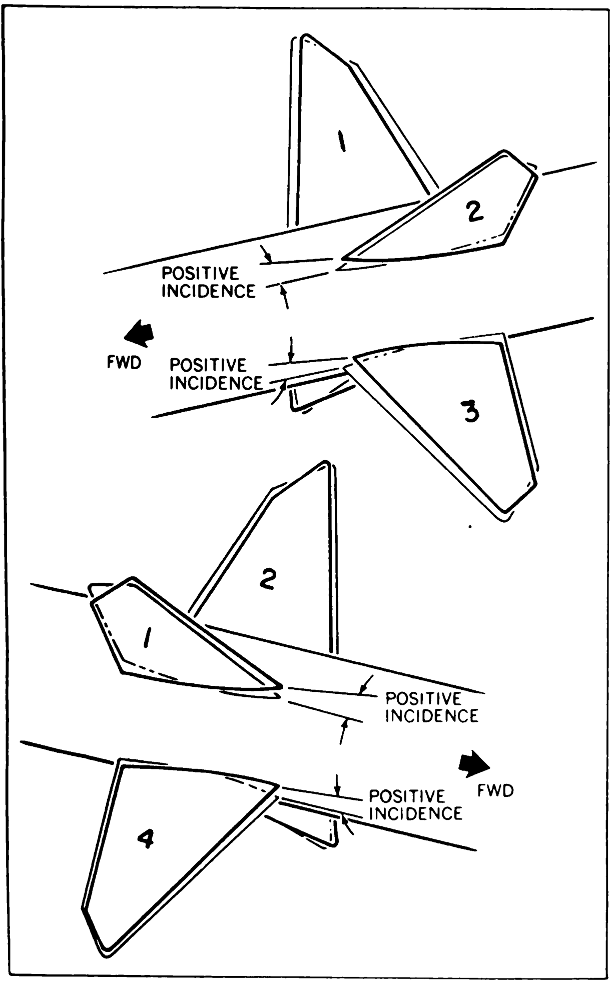

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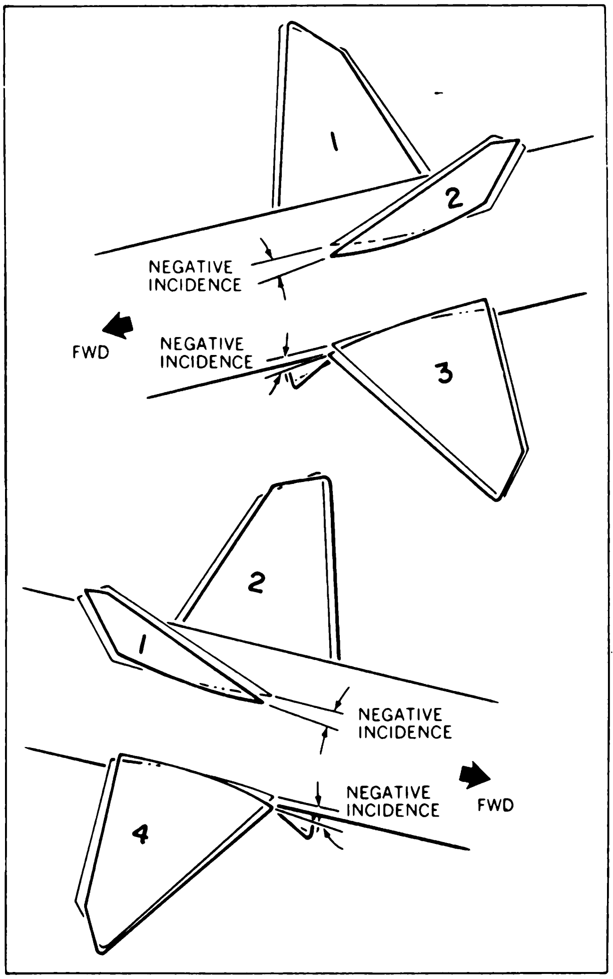
Figure 2-24.—Wing movements for climb.



167.3
Figure 2-25.—Wing movements for dive.

Consequently, greater maneuverability can be secured with a given control surface area. The mechanical advantage of levers is presented in Basic Machines, NavPers 10624-A. It would be to your advantage to review this part of the basic text.

Control Action

The external control surfaces of guided missiles (wings and fins) and the effect of natural forces acting on them have been described in the previous paragraphs. The following paragraphs tell how the control surfaces are controlled to keep the missile in its proper attitude on its ordered trajectory.

FACTORS CONTROLLED.—Missile course stability is made possible by devices which control the angular movement (also called rotational movement) of the missile about its three axes. The three flight control axes are shown in figure 2-15. These are the pitch, yaw, and roll axes. The second type of movement called translation includes a linear movement of the missile. For example, a sudden gust of wind or an air pocket could throw a missile a considerable distance off the desired trajectory without causing any significant angular movement. Any linear movement, regardless of direction, can be resolved into three components: lateral movement, vertical movement, and movement along the

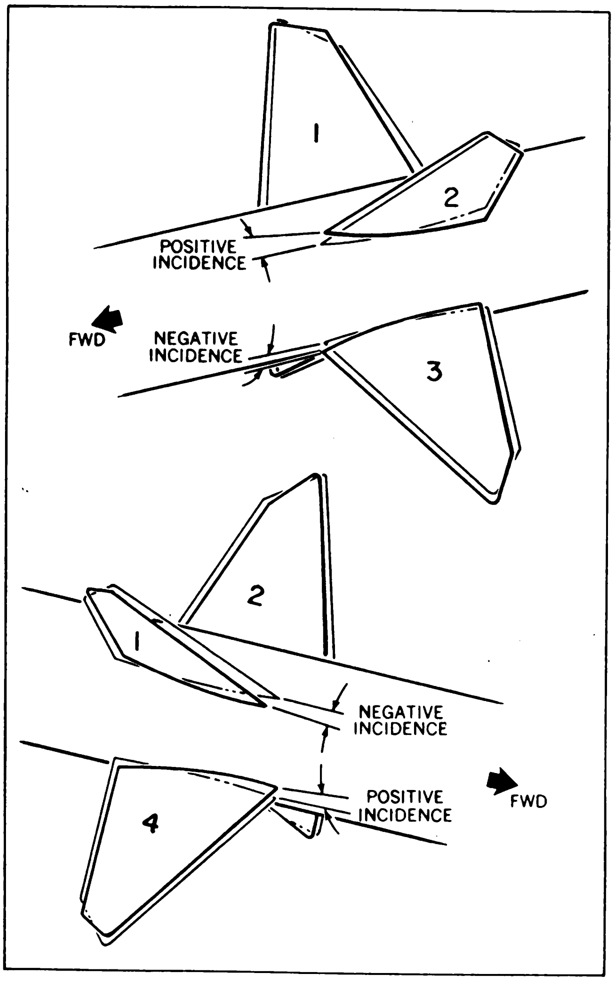


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Figure 2-26.—Wing movements for level right turn.

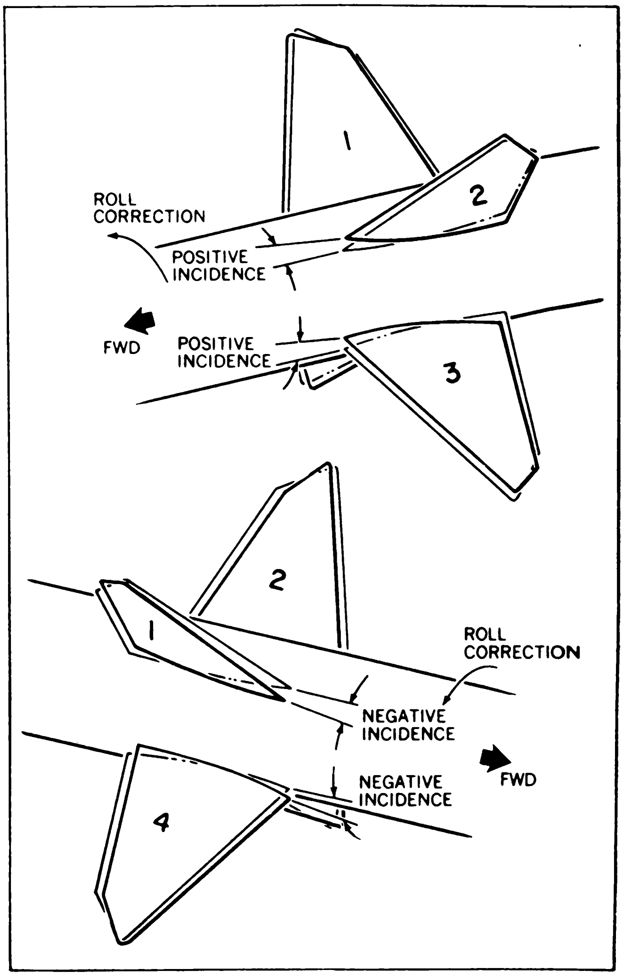

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Figure 2-27.—Wing movements for roll.

direction of the thrust. Thus, in addition to the three angular degrees of movement, there are three linear degrees of movement. A missile in flight can therefore be said to have six degrees of freedom.

TYPES OF CONTROL ACTION.—The basic control signals may come from inside the missile, from an outside source, or both. To coordinate the signals, computers are used to mix, integrate, and rate the signal impluses. In a missile control subsystem, the remembering is done by integrating devices and the anticipation (of what to do next) is done by rate devices.

The computer network can be thought of as the brain of the missile. The computer network takes into account guidance signals, missile movement, and control surface positions. By doing this continuously, it can generate error signals. These signals cause control surface (wing and/or fin) movements that tend to keep the missile at its design attitude and on its correct trajectory. Like a ship, the missile continuously yaws, rolls, and pitches, and experiences movements of translation. The computer network can be compared to the helmsman on a ship. Both are always making corrections. Seldom is either absolutely right.

The terms "error signal" and "correction signal" are used almost interchangeably. Strictly speaking, the signal that orders movement of the control surfaces to correct errors is a correction signal. It originates in the control section of the missile. Signals that tell the computer about deviations in flight path are error signals and originate in the guidance subsystem. Since all of these signals concern errors, they may be called error signals.

An automatic control system, using these principles, is generally referred to as servomechanism, discussed in chapter 9 of this textbook.

REQUIREMENTS OF A MISSILE-CONTROL SERVOSYSTEM.—It was stated before that the missile control subsystem is a servomechanism. In performing its function, a servomechanism takes an order and carries it out. In carrying out the order, it determines the type and amount of difference between what should be done and what is being done. Having determined this difference, the servomechanism then goes ahead to change what is being done to what should be done. In order to perform these functions, a servomechanism must be able to:

1. Accept an order which defines the result desired.
2. Evaluate the existing conditions.
3. Compare the desired result with the existing conditions, obtaining a difference between the two.
4. Issue an order based on the difference so as to change the existing conditions to the desired result.
5. Carry out the order.

For a servomechanism to meet the requirements just stated, it must be made up of two systems—an error detecting system and a controlling system. The load device which is connected to the output of the servo, can be considered part of the controller.

By means of servosystems, some property of a load device is made to conform to a desired condition. The property under control is usually the position, the rate of rotation, or the acceleration of the load. The system may be composed of electrical, mechanical, hydraulic, pneumatic, or thermal units, or of various combinations of these units. The load device may be any one of an unlimited variety; a missile control surface (wing or fin), the output shaft of an electric motor, and a radar tracking antenna are a few typical examples.

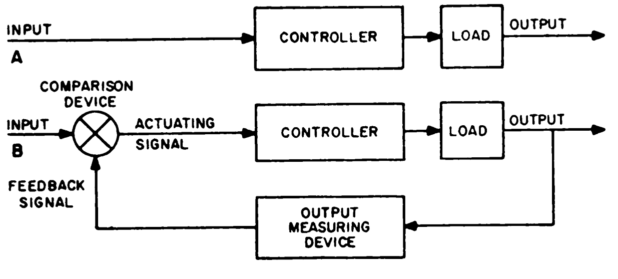
OPEN AND CLOSED-LOOP SERVOSYSTEMS.—Automatic servosystems can be divided into two basic types: Open-loop and closed-loop systems, as illustrated in figure 2-28. In both systems, an input signal must be applied which represents in some way the desired condition of the load.

In the open-loop system, the input signal is applied to a controller. The controller positions the load in accordance with the input. The characteristic property of open-loop operation is that the action of the controller is entirely independent of the output.

The operation of the closed-loop system involves the use of feedback. The output as well as the input determines the action of the controller. The system contains the open-loop components plus two elements which are added to provide the feedback function. The output position is measured and a feedback signal proportional to the output is fed back for comparison with the input value. The actuating signal is a signal which is proportional to the difference between input and output. Thus, the system operation is dependent on input and output rather than on input alone.

Of the two basic types, closed-loop control (also called feedback control) is by far the more widely used, particularly in applications where speed and precision of control are required. The superior accuracy of the closed-loop system results from the feedback function which is not present in open-loop systems. The closed-loop device goes into operation automatically to correct any discrepancy between the desired output and the actual load (missile wing and fin) position, responding to random disturbances of the missile wings and fins as well as to changes in the input signal.

CONTROLLABLE FACTORS.—The missile control subsystem is actually a closed-loop servomechanism in itself. It is able to detect



167.706

Figure 2-28.—Basic types of automatic servosystems.

roll, pitch, and yaw, and is able to position the moveable wings and/or fins in accordance with this attitude information. It is important to understand that the wings and fins are not positioned on the basis of attitude information alone. It is again pointed out that movement information, guidance signals, and wing position information are continuously analyzed in the missile computer network. The correction signals are continuously generated on the basis of all this information.

OVERALL OPERATION.—A basic missile control system in block diagram form is given in figure 2-29A. Free gyroscopes provide inertial references from which missile attitude can be determined. For any particular missile attitude, gyro signals are sent from the gyroscopes to the computer summing network of the missile.

These signals are proportional to the amount of roll, pitch, and yaw at any given instant. After these signals have been compared with other information (for example, guidance signals), correction signals result. The correction signals are orders to the controller to position the control surfaces (wings and/or fins). The purpose of the amplifier is to build the weak correction signals up to sufficient strength to cause actuation of the controller. As in any closed-loop servosystem, feedback information plays an important role. A feedback mechanism continuously measures the position of the wings and fins and relays signals back to the computer network.

In addition to the internal feedback which is actually measured by a mechanism, we can think of the missile's movement detecting devices as providing an external feedback feature. The fact that the gyroscopes continuously detect changing missile attitude introduces the idea of external feedback. This is represented by the dotted line in figure 2-29A.

ELEMENTS OF MISSILE CONTROL SUBSYSTEMS.—The elements of a missile control subsystem may be grouped according to their functions. They cannot be strictly compartmentalized as they must work together and there is overlapping. Devices for detecting missile movement may be called error-sensing devices. The amount and direction of error must be measured by a fixed standard; reference devices provide the signal for comparison. Correction-computing devices compute the amount and direction of correction needed and correction devices carry out the orders to correct any deviation. Power output devices amplify the error signal, but the prime purpose is to build up a small computer output signal to a value great enough to operate the controls. The use of feedback loops provide for smooth operation of the controls.

GUIDANCE

Purpose and Function

The purpose of a guidance subsystem is to determine the path of the missile while it is in flight. This makes it possible for personnel at the launching ship to hit a desired target, regardless of whether or not it takes deliberate evasive action. The guidance function may be based on information provided by sources inside the missile, on information sent from the launching ship, or both.

Thus, the missile guidance subsystem is essentially a part of the weapon control system inherently associated with the weapon direction phase. Although guidance and control subsystems have distinct functions, they must operate together. The guidance subsystem detects and tracks the target, determines the desired course to the target, and produces the electrical steering signals that indicate the required path; the control subsystem responds to the signals to keep the missile on course, figure 2-29B.

The operation of the guidance and control subsystems is based on the closed-loop or servo principle. The control units make corrective adjustments of the missile wings and/or fins when a guidance error is present. The control units will also adjust the wings and/or fins to stabilize the missile in roll, pitch, and yaw. Guidance and stabilization are two separate processes although they occur simultaneously.

Phases of Guidance

Missile guidance is generally divided into three phases (figure 2-30)—boost, midcourse, and terminal. These names refer to different parts of the flight path. The boost phase may also be called the launching or initial phase.

INITIAL (BOOST) PHASE.—Navy surface-to-air missiles are boosted to flight speed by means of the booster component. This boosted period lasts from the time the missile leaves the launcher until the booster burns up its fuel. In

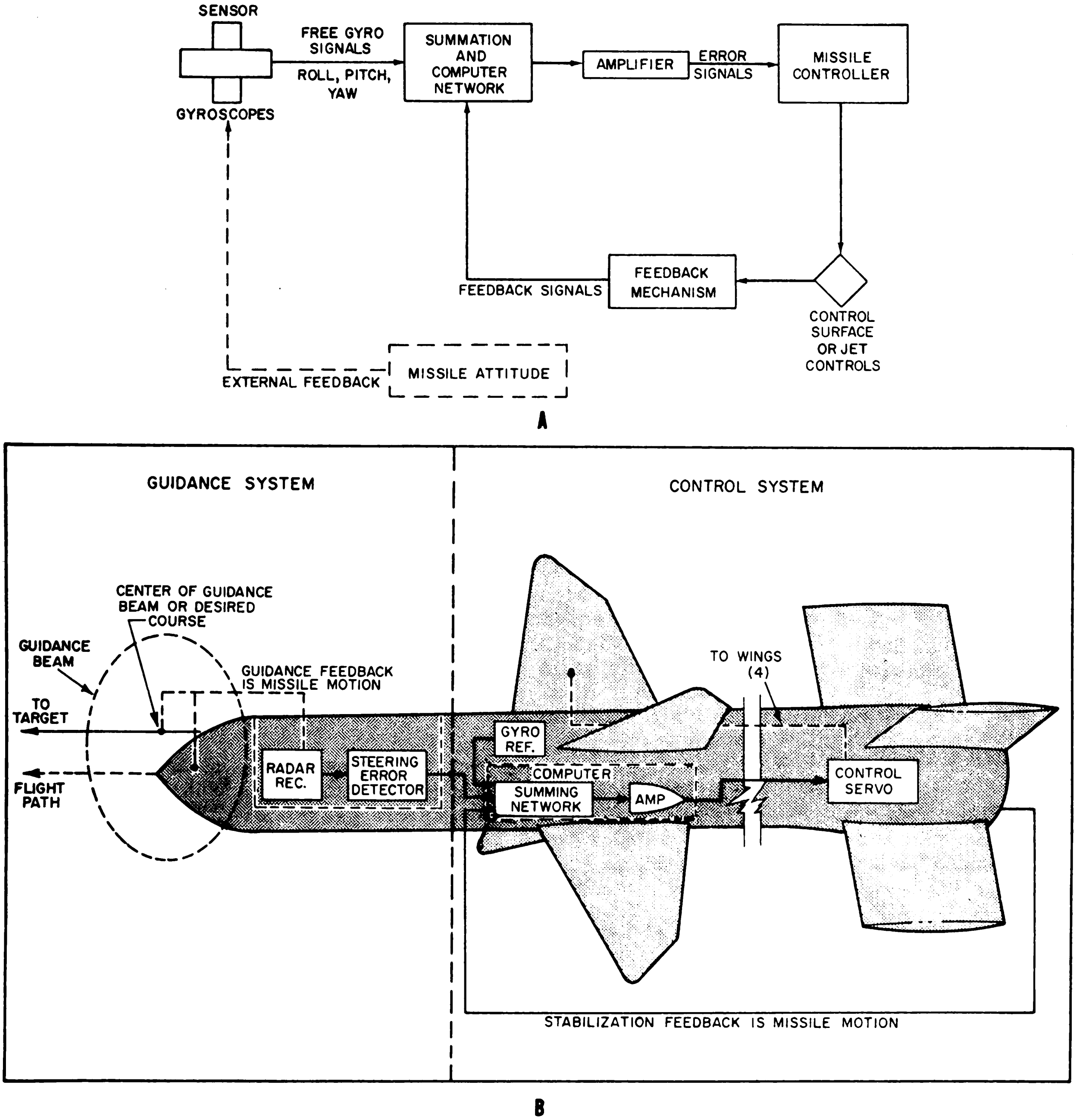


Figure 2-29.—Basic missile guidance and control systems.

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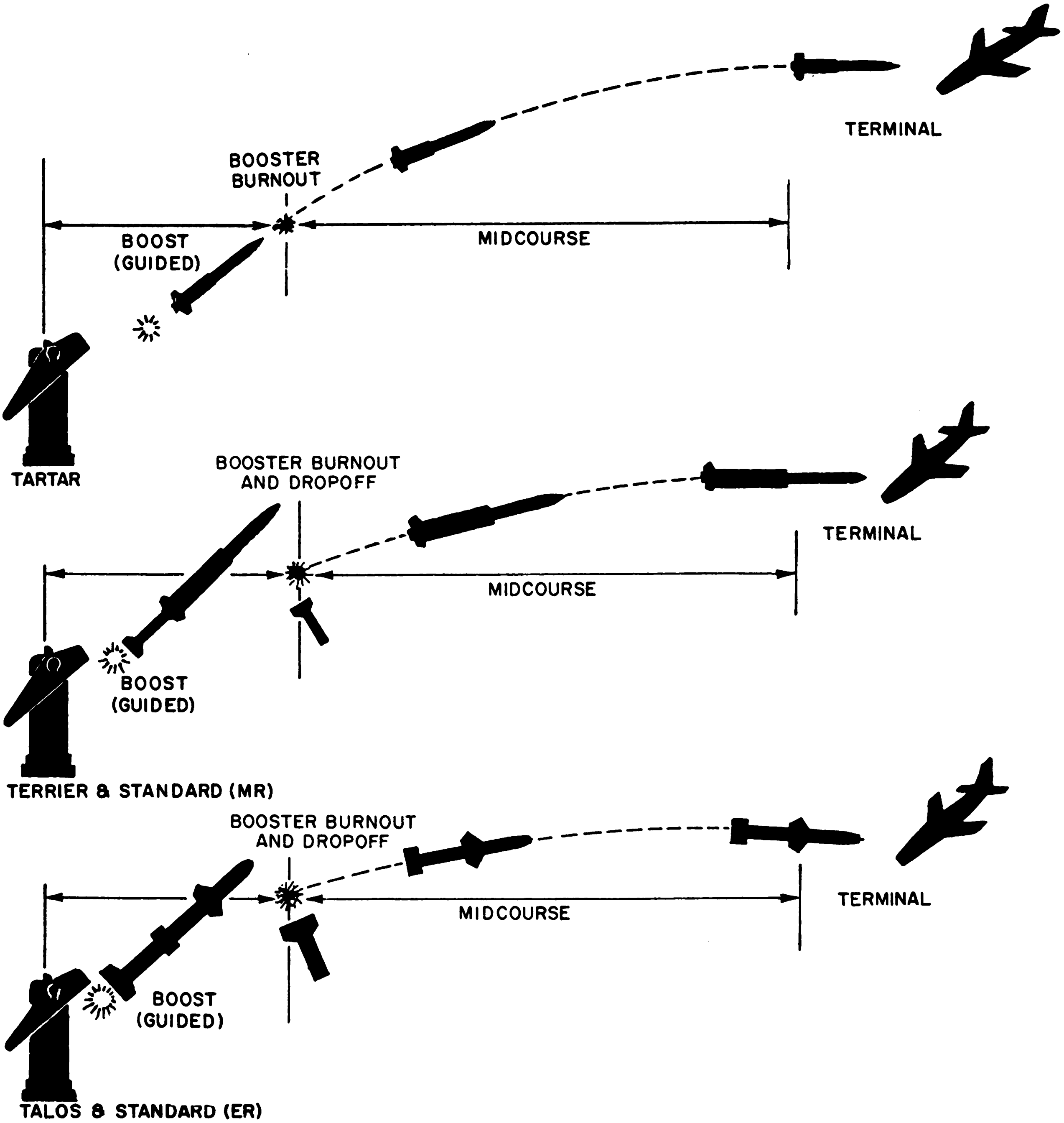

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Figure 2-30.—Guidance phases of missile flight.

missiles with separate boosters, the booster drops away from the missile at burnout. Discarding the burnt out booster shell reduces the drag on the missile and enables the missile to travel farther.

The problems of the initial phase and the methods of solving them vary for different missiles and their means of projection. However, the basic purposes are the same. The boost phase must get the missile off to a good start or it will not hit the target. The launcher, holding the missile, is aimed in a specific direction on orders from the fire control computer. This establishes the line of sight (trajectory or flight path) along which the missile must fly during the boosted portion of its flight. At the end of the boost period the missile must be at the calculated point.

There are several reasons why the boost phase is important. If the missile is a homing missile, it must "look" in the predetermined direction toward the target. The fire control computer (on the ship) calculates this predicted target position on the basis of where the missile should be at the end of the boost period. Before launch, this information is fed into the missile.

When a beam-riding missile reaches the end of its boosted period, it must be in a position where it can be captured by the radar guidance beam. If the missile does not fly along the prescribed launching trajectory as accurately as possible, it will not be in position to be captured by the radar guidance beam to continue its flight to the target. The boost phase guidance system keeps the missile heading exactly as it was at launch.

During the boost phase, in some missiles (fig. 2-30), the missile's guidance system and the aerodynamic surfaces are locked in position. Some missiles (for example, Talos) are guided during the boost phase.

MIDCOURSE PHASE.—The second, or midcourse phase of guidance is often the longest in both distance and time. During this part of the flight, changes may be required to bring the missile onto the desired course, and to make certain that it stays on that course. During this guidance phase, information can be supplied to the missile by any of several means. In most cases, the midcourse guidance subsystem is used to place the missile near the target, where the subsystem to be used in the final phase of guidance can take over. In some cases, the midcourse guidance subsystem is used for both the second and third guidance phases.

TERMINAL PHASE.—The terminal phase is of great importance because it can mean a hit or a miss. The last phase of missile guidance must have high accuracy as well as fast response to guidance signals.

Near the end of the flight, the missile may lack the power necessary to make the sharp turns that are required to overtake and score a hit on a fast-moving target.

In some missiles, especially short-range missiles, a single guidance subsystem may be used for all three phases of guidance. Other missiles may have a different guidance subsystem for each phase.

Beam-Rider Guidance

This section will give information of a general nature on beam rider guidance. It should be kept in mind that security requirements prevent a detailed description of the guidance system of any specific missile. The three supplements to this textbook, namely TALOS, TERRIER, and TARTAR/BASIC POINT DEFENSE, will give you a more detailed description of missile guidance and should be studied to enhance your knowledge of this subject.

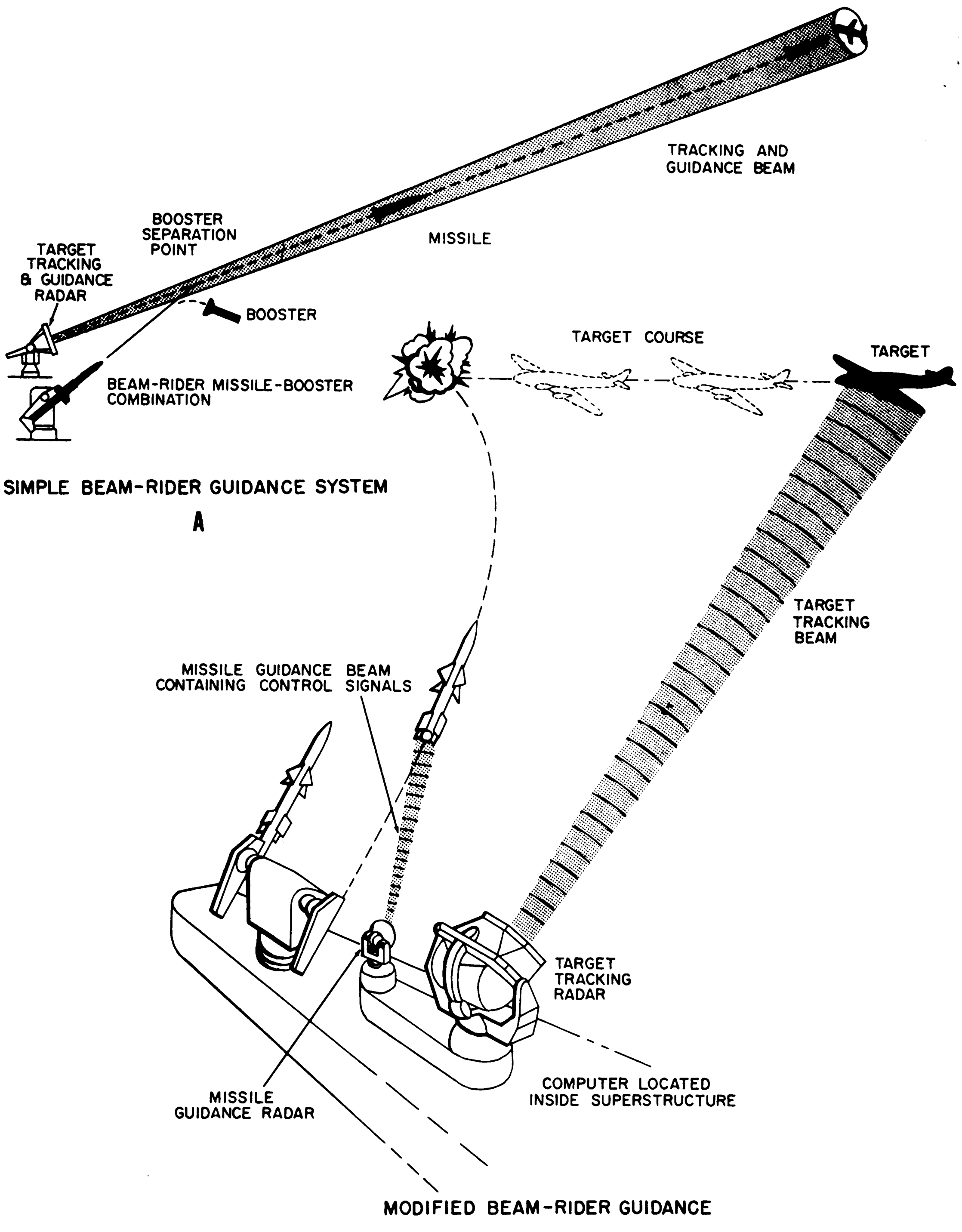
In the beam-rider guidance system, the missile has been designed so that it is able to formulate correction signals on the basis of its position with respect to the radar scan axis.

A computer in the missile keeps it centered in the radar beam. It locates the center of the beam and sends the necessary signals to the control subsystem to remain in it. The radar keeps the beam pointed at the target and, if desired, several missiles may "ride" the beam simultaneously. Figure 2-31A illustrates a simple beam-rider guidance subsystem. The accuracy of this system decreases with range because the radar beam spreads out and it is more difficult for the missile to remain in its center. If the target is moving, the missile must follow a continuously changing path, which causes it to undergo excessive transverse accelerations.

A modified beam-rider subsystem uses two radars, a target-tracking radar and a missile guidance radar (figure 2-31B). The target-tracking radar feeds target data into the fire control computer, which calculates a collision point at which the missile will intercept the target. The second radar is programed by the fire control computer and pointed toward the calculated collision point. The missile follows this beam.

The missile guidance radar transmits information to the missile. It indicates the direction of the target or the calculated point of interception. The guidance subsystem within the missile must interpret the information and then formulate its own correction signals. The missile is said to "ride" the beam to the target.

The receiving antenna in the missile is a very important part of its electronic installation. Through it must come all guidance signals from the control radar. There are several


TRACKING AND GUIDANCE BEAM
BOOSTER SEPARATION POINT
MISSILE
TARGET TRACKING & GUIDANCE RADAR
BOOSTER
BEAM-RIDER MISSILE-BOOSTER COMBINATION
TARGET COURSE
TARGET
SIMPLE BEAM-RIDER GUIDANCE SYSTEM
A
TARGET TRACKING BEAM
MISSILE GUIDANCE BEAM CONTAINING CONTROL SIGNALS
TARGET TRACKING RADAR
COMPUTER LOCATED INSIDE SUPERSTRUCTURE
MISSILE GUIDANCE RADAR
MODIFIED BEAM-RIDER GUIDANCE

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12.33

Figure 2-31.—Beam-rider guidance.

difficulties in determining the optimum location of an antenna on a missile. First, the antenna must not interfere with the aerodynamic stability of the missile. Second, it must be located at a point where it will not be damaged by the rapid acceleration as the missile is launched, and where wind will not tear it loose. Finally, the antenna must be located where it can effectively pick up the signals of the guidance beam. The antenna location that has been found most satisfactory is at or near the missile after surfaces.

The missile antenna is highly directional, and most sensitive to signals received from behind the missile. The roll-control system of the missile keeps it stabilized so that the antenna polarization remains constant. Another purpose of the roll-control system is to establish an up-down, right-left guidance coordinate.

The guidance signals picked up by the missile antenna are fed to a receiver. After the signals are amplified and demodulated by the receiver, they are fed to a computing network in the missile. Demodulation is the process of extracting information (direction, etc.) about the target from the beam's carrier signal. If the missile is off the scan axis of the guidance beam, the computer will determine both the direction and the magnitude of the error. It will then give the correction signals required to bring the missile back onto the scan axis.

Figure 2-32 is a block diagram of the essential components of a beam-rider guided missile. The computer includes all the necessary circuitry to separate the up/down and left/right correction signals contained in the output of the receiver. The separate signals are then amplified and drive the servomotors which actuate aerodynamic surfaces or other means of control to change the position of the missile and cause it to move toward the center of the beam.

The missile also needs to be roll-stabilized. This is done by placing a gyroscope inside the missile with its axis oriented so that an output is produced if the missile tends to roll. The output is amplified to operate control surfaces that neutralize the tendency of the missile to roll.

Semiactive Homing System

In a semiactive homing system, the target is illuminated by some means outside the target or the missile. Radar is used for this type of homing guidance by sending a radar beam to the target. The beam is reflected from the target and picked up by equipment in the missile. The radar transmitter is located aboard the launching ship.

Semiactive homing is used for all or part of the trajectory of several of our best-known missiles, including TERRIER, TALOS, and TARTAR.

The missile, throughout its flight, is between the target and the radar that illuminates the target. It will receive radiation from the launching ship, as well as reflections from the target. The missile must therefore have some means for distinguishing between the two signals, so that it can home on the target rather than on the launching ship. This can be done in several ways. For example, a highly directional antenna may be mounted in the nose of the

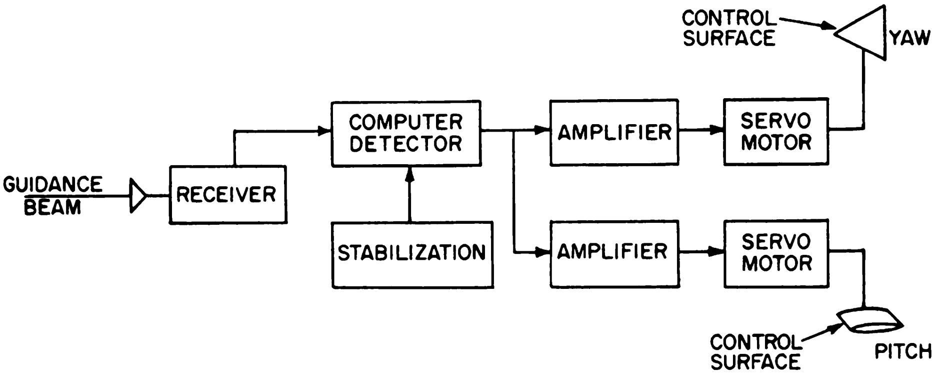

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Figure 2-32.—Beam-rider guided missile, block diagram (essential components).

missile. Or the doppler principle may be used to distinguish between the transmitter signal and the target echoes. Since the missile is receding from the transmitter, and approaching the target, the echo signals will be of a higher frequency.

The radar receiving antenna in the head of the missile is called the seeker or seeker head. It receives echoes from the target. The semiactive homing antenna system locates the target and automatically tracks it. The tracking process locates the line of sight between the target and the missile. A computer in the guidance system uses this tracking information to produce steering signals. The missile, however, does not fly along a line of sight, but follows a collision course, or rather, a refined collision course. The missile receives this refinement before it is launched. It receives this navigational information through the warmup contactor of the launching system. Most of our missiles are given a warmup period just before loading on the launcher and a final warmup while on the launcher, just before firing.

To intercept high-speed targets like a supersonic aircraft or a missile, the semiactive homing missile must follow a lead (collision) course. If the target flies a straight-line constant-velocity course, the missile can also follow a straight-line collision course if its velocit does not change. In actual situations, ther usually are variations in speed, change in patl maneuvers of the target, etc. The missile ha to adjust its direction to maintain a constar bearing with the target. The components in th missile must be able to sense the changes an make the necessary adjustments in its cours to the target. Missile velocity seldom is constant. Irregular propellant burning changes thrus and therefore affects speed. Wind gusts and/o air density can change the speed and path o the missile. The same factors can influence th target. The missile must use proportional navigation to achieve target intercept. If the missil path is changed at the same rate as the targe bearing (fig. 2-33A), the missile will have t turn at an increasing rate (positions 1 to 6) and will end up chasing the target (positions 6 and 7). This flight path follows a pursuit curve and the missile cannot maintain a constant bearin with the target. It is just keeping up with change in target bearing and may not be able to catcl up with the target.

To achieve the desired straight-line course during the final and critical portion of the attack, the missile must turn at a rate greater than the line of sight is turning. By overcorrecting the missile path, a new collision

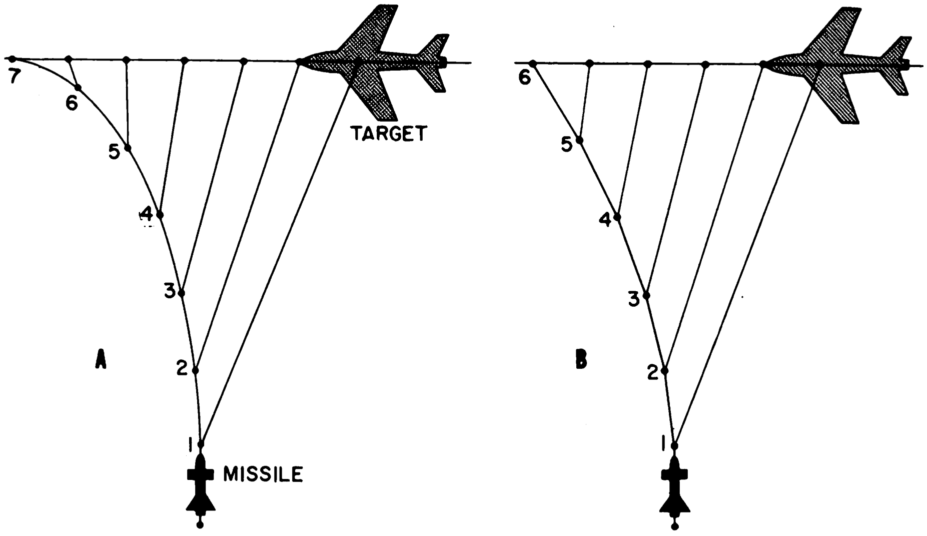

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Figure 2-33.—Proportional navigation: A. Pursuit curve; B. Overcorrection to produce proportional navigation.

heading is reached and the bearing angle will remain almost constant, especially near intercept. This technique results in a proportional navigaion course (fig. 2-33B). It is sometimes called the N factor, or navigation ratio, which is the ratio of the rate of turn of the missile to the rate of turn of the line of sight (rate of change of target bearing). The missile fire control computer on shipboard computes the ratio and transmits it to the missile launching system for transfer to the missile's guidance and control system.

For the purposes of this text, we can think of the missile guidance components as divided into several distinct sections. These are shown in block diagram form in figure 2-34. Note that these are the components in the missile; launching station guidance components are not shown.

In semiactive homing systems, the missile receiving antennas and associated equipment must be designed in such a way as to produce directional information which will enable the missile to be guided to the target.

To carry out this function, the receiving antennas are mounted in a gyro-stabilized homing head. The gyros provide the up-down, right-left references on which the missile will base its maneuvers to approach the target by the proportional navigation method.

Radar is generally used for semiactive homing guidance. The antenna in the missile must therefore be capable of detecting radiation at radar frequencies. It is mounted in the nose of the missile, since information is being obtained from the target area and the missile is approaching the target nose first. When a beam-riding system is used for the intermediate phase of guidance, a separate beam-rider antenna is mounted near the tail of the missile. Some missiles with a semiactive homing system also have a small antenna at the after end of the missile, rearward-looking, to receive illuminator energy directly from the illuminator radar. This rear signal is used as a reference to which the front signal is compared to determine the missile-target closing rate. This closing rate (range rate) is detected by measuring the Doppler effect which causes a frequency difference between the incoming front and rear signals. The Doppler shift is proportional to the range rate. The range rate, plus antenna turning rates and position, are supplied to the autopilot, which steers the missile on a proportional navigation course to intercept.

In some systems, the homing guidance antenna may use a form of conical (or nutating) scan in order to take full advantage of the guidance signal. Conical scanning (fig. 2-35) has the advantage that the antenna can receive signals from points off the missile axis. This decreases the chance that the missile, while homing, may lose its target and go out of control. The drive unit keeps the antenna continually pointed at the target.

A radar-type receiver must be used in the missile when radar is used for semiactive homing. The signals picked up by the antennas as it scans the target area are fed into the receiver. The receiver operates in a conventional manner. The signals at the output of the receiver are

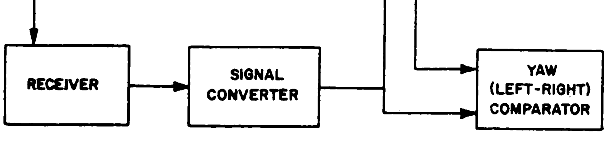

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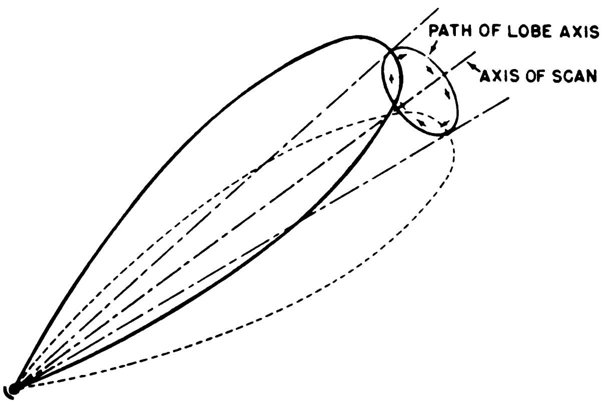
Figure 2-34.—Semiactive homing system; block diagram.



33.113
Figure 2-35.—Nutating lobe, conical scanning.

not suitable for use in activating the missile flight controls without further processing.

The receiver output is fed to the signal converter, which changes the signal to a form that can be used for comparison with signals from another section of the missile electronic equipment.

The reference unit furnishes the comparison signal. This information might be placed in the missile just prior to launching or transmitted as an FM signal to the missile in flight. It could be stored in a variety of forms, such as magnetic wires, magnetic tapes, punched paper tapes or punched cards. Before a guidance system can function, an error signal must be produced. The error in flight path, if any, can be determined by comparing the reference signal and the signal from the converter section. Comparison of the two signals takes place in other sections of the missile electronic equipment.

The missile flight controls may be used to correct the lateral or vertical trajectory of the missile. Since it is possible for the missile to be on the right course vertically but off course laterally, two comparators are used. The output from the reference unit and the output from the signal converter are fed to both the pitch and yaw comparators.

Should there be no difference in the two signals at either comparator, the controls would remain in neutral position. However, should there be a difference in the two signals at either comparator, error signals will be generated. The error signals are not suitable for use in controlling the missile flight surfaces and must be sent to other sections of the guidance system before they can be used.

The missile flight control surface operation is controlled by autopilots. These devices are a combination of gyroscopes and electrical units which will be described elsewhere in this manual. The autopilot controls operation of the hydraulic or electric system which, in turn operates the flight control surfaces. There are two autopilots — one for the pitch control surfaces and one for the yaw control surfaces.

WARHEADS

The guided missile must carry some form of useful burden — a payload — if it is to accomplish its mission. Every action of the missile serves as a means to deliver its payload. In training missiles, the payload often includes telemetering units, which collect data during the flight, convert it into radio signals, and transmit the information to receivers aboard ship. The training missiles carry dummy payloads which have the same physical characteristics as an operational weapon. In its military role, the guided missile's payload consists of one or more WARHEADS and one or more FUZES. The warhead is capable of destroying an enemy target. The fuze is a triggering mechanism used to initiate the actions of the warhead.

The basic warhead consists of three functional parts: a payload, a fuze, and a safety and arming (S&A) device. Variations in warhead type are obtained by altering any or even all three elements. The warhead of a guided missile generally has a separate payload, fuze, and safety and arming device.

Some of the types of warheads that may be used in guided missiles are blast-effect, fragmentation, shaped-charge, explosive-pellet, chemical, biological, and nuclear or thermonuclear.

PAYLOAD

The primary element of the warhead is the payload, defined as the destructive agent of the warhead, or that portion of the warhead which accomplishes the desired end result.

Blast-Effect Warheads

This type of warhead causes damage by means of a high-pressure wave or blast, which results from the detonation of high-explosive material. Blast warheads are very effective against ground targets. They are less effective against aerial targets since the pressure wave dissipates rapidly in air.

Fragmentation Warheads

These warheads operate by bursting a metal case containing a high-explosive charge. Upon explosion, the container is shattered into hundreds of fragments which fly out at high velocities; and these are capable of damaging targets at considerable distances from the point of detonation. For this reason, this sort of warhead is very effective against aerial targets. Usually the warhead does not penetrate the target but is detonated by the fuze at a distance which allows the full destructive effect to be realized.

The continuous rod warhead (fig. 2-36) is a controlled fragmentation type warhead used extensively on SMS missiles. Upon detonation, the

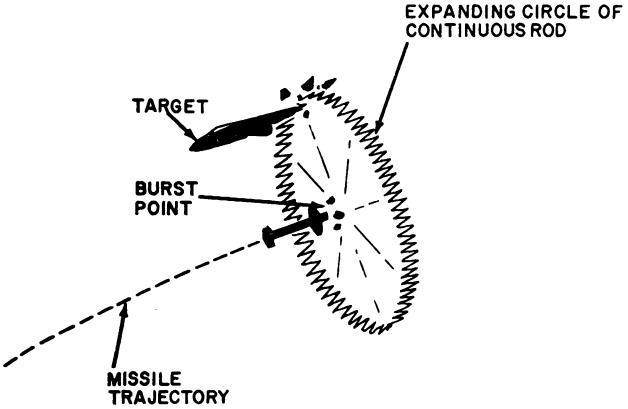


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Figure 2-36.—Expansion of continuous rod warhead.

continuous rod warhead expands radially into a ring pattern. The intent is to cause the connected rods, during their expansion, to strike the target and produce damage by a cutting action. Connected rods generally form two semicircles as they expand. This prevents disintegration of the circular pattern when maximum expansion is reached.

Shaped-Charge Warheads

The amount of explosive power released from a shaped charge or "cavity charge" depends on the shape of the explosive material.

Experiments show that if a regular cavity such as a conical hole is molded into the side of an explosive charge nearest the target, the effect on the target is greatly increased. The presence of the hole brings about a concentration of the explosive force in much the same way light is focused into an intense beam by a lens.

Explosive-Pellet Warheads

A warhead of this type contains a number of small explosive charges or pellets, each of which is separately fuzed. When the main warhead is detonated, the pellets are ejected but withstand the force of the explosion and are hurled intact toward the target. The pellets then detonate either on impact or after penetrating the target skin. The total destructive effect combines both blast and fragmentation effects, since blast damage is great when the individual charge is exploded, regardless of whether the explosion occurs at the skin of the target or after penetrating it.

Chemical Warheads

This type may contain either war gases or incendiary materials. Warheads containing gases may liberate any of the well-known types such as mustard gas or lewisite, or some newly developed chemical. The effects produced are either denial of the use of the target area or personnel casualties within the area.

The incendiary warhead contains a material that burns violently and is difficult to extinguish, while covering a large area after release from the warhead. Incendiary weapons are useful principally against ground targets.

Biological Warheads

A biological weapon delivered by a missile would contain living organisms capable of disrupting personnel activities in the target area by causing sickness or death to the inhabitants.

Nuclear and Thermonuclear Warheads

In this type, destruction and damage result from the processes of atomic fission or fusion. The destructive effects are blast, heat, and radiation. The detonation results in death, sickness, and the denial of the use of large areas as a result of the release of radioactive elements.

FUZES

The fuze is that part of the warhead which initiates detonation of the payload. In guided missiles the fuze is referred to as the Target Detection Device (TDD). For an attack to be effective, detonation must occur at the time during the missile's trajectory that will cause maximum damage to the target. Called the "optimum time of detonation", it is determined by the nature of the target and the attack geometry involved. If effectively designed, the fuze will always recognize and initiate detonation at this optimum time. Some method of obtaining the required data is necessary. The data may be derived from energy which is either generated or influenced by the target, or from the motion of acceleration of the missile. The fuze may perform this data-gathering function independently or may be supplied with the required data by a central data-gathering system which also supplies data to other components of the missile, such as the guidance system.

The missile warhead is activated by the actions of one or more fuzes, which release the destructive forces after certain conditions have been fulfilled. The type of fuzing employed determines whether the warhead is detonated at a distance from the target, upon impact with it, immediately following penetration, or at some fixed time after penetration of the target skin. The missile warhead is generally detonated at one of the three time relations with the target shown in figure 2-37.

The most effective type of fuze for a given missile depends upon the nature of the target and the possibilities of the warhead for causing damage. The types often employed in missiles are the IMPACT, GROUND-CONTROLLED, and PROXIMITY fuzes.

Impact Fuzes

Impact fuzes are actuated by the inertial force exerted when the missile strikes the target. If detonation takes place at the moment of impact, the fuze is of the NON-DELAY, or INSTANTANEOUS type. If the detonation takes place some time after penetration, the fuze is said to be of the DELAY type.

Ground-Controlled Fuzes

In ground-controlled fuzes, some device is used for measuring the distance from the missile to the target. The control device is not mounted in the fuze but on the ground; and when the proper space relationship exists between the missile and its target, a signal is sent to detonate the fuze from the control point on the ground.

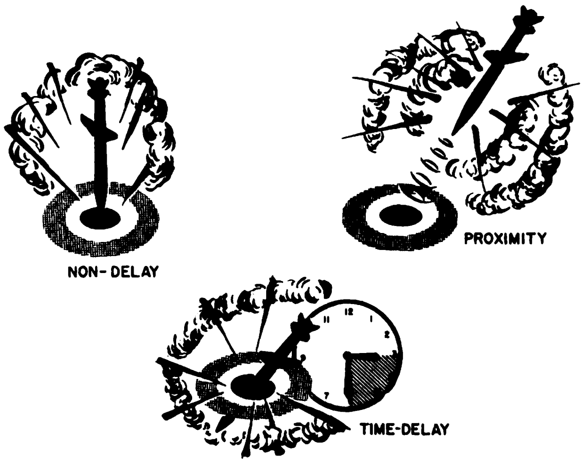

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Figure 2-37.—Types of fuzing.

Proximity Fuzes

Fuzes of this type are actuated by the influence of some property of the target and are detonated at a distance which allows maximum damage to take place. Five general classes of proximity (also called VT, or variable-time) fuzes can be distinguished according to the property to which the device responds. These are radio, pressure, acoustic, photoelectric, and electrostatic fuzes.

Radio fuzes contain miniature transmitters and receivers. In flight, radio signals are radiated, some of which are reflected by the target. At the proper time, the action of the reflected waves causes an electronic switch to close and fire the detonator. Fuzes of this kind have been developed to a high degree of accuracy and dependability. They operate effectively in both darkness and daylight and in all kinds of weather.

Proximity fuzes which respond to changes in pressure generally lack the sensitivity and reliability required for guided missile applications, but in some cases they are useful against surface targets.

Acoustic fuzes, which respond to sound, have the valuable property of all-weather, day-or-night effectiveness; but they also have a disadvantage in that they are subject to local vibrations.

The possibilities of the electrostatic system of fuzing in which the detonating influence is the electric field of the target have also been explored. Attempts to develop the fuze were unsuccessful—probably because of the variable nature of the electrostatic field surrounding possible targets. Photoelectric fuzes react to external light sources and ordinarily are inoperable at night or in conditions of low visibility.

Of these various types of proximity fuzes the radio system has proved to be the most reliable and effective for missile applications.

SAFETY AND ARMING

The safety and arming (S&A) device performs two sequential functions within the warhead. First, it prevents accidental detonation of the warhead (safety feature) by interrupting the path between the fuze and the payload until it is ascertained that detonation will not be dangerous to friendly forces. Secondly, it provides a detonation path (arming feature) between the fuze and the payload, after safety has been assured, by removing the interruptor. The S&A device thus acts as an open switch until safe detonation can be accomplished, and is then closed thereafter. Normally the method employed to accomplish the safety function is to insert a physical barrier between the fuze and the payload.

In some cases the S&A device is used to destroy the missile by initiating the payload or another destructive charge if the target is not met and there is a chance that the missile may become a danger to friendly forces. As a secondary consideration, it is often desirable to delay arming until just before optimum detonation due to incorrect fuze action caused by, for example, enemy countermeasures.

PROPULSION

The underlying principle of propulsive movement has been stated by Newton in his Third Law of Motion: To every action there is an equal and opposite reaction. Every forward acceleration or change in motion is a result of a reactive force acting in the opposite direction. A person walks forward by pushing backwards against the ground. In a propeller-type airplane, the air through which it is moving is driven backward to move the airplane forward. In a jet-propelled plane or a rocket, a mass of gas is emitted rearward at high speed, and the forward motion of the plane is a reaction of the motion of the gas. Matter in the form of a liquid, a gas, or a solid may be discharged as a propellent force, expending its energy in a direction opposite to the desired path of motion, resulting in a predetermined acceleration of the propelled body along a desired trajectory.

CLASSIFICATION OF JET SYSTEMS

Jet propulsion systems used in guided missiles may be divided into two types: Ducted propulsion systems (TALOS) and rocket systems (TERRIER, TARTAR, STANDARD, and SPARROW III).

Missiles using a ducted propulsion system are air-breathing missiles; they are incapable of operating in a vacuum. The missile takes in a quantity of air at its foward end, increases its momentum by heating it, and produces thrust by permitting the heated air and fuel combustion products to expand through an exhaust nozzle. This process may be broken down into the following steps: air is taken in and compressed; liquid fuel is injected into the compressed air; the mixture is burned; and the resulting hot gases are expelled through a nozzle. The air may be compressed in any of several ways. In a turbojet engine, air is compressed by a rotary compressor, which in turn is operated by a turbine located in the path of the exhaust gases and mounted on the same shaft as the compressor. (A turboprop engine, now used in some manned aircraft but not in guided missiles, makes use of a propeller mounted at the forward end of the compressor turbine shaft.) In a pure duct system, such as the ramjet, air is compresssed by the forward motion of the missile through it. The now obsolete pulsejet also depends on forward motion for compression. It differs from the ramjet in that combusion is intermittent, rather than continuous.

Rockets do not depend on air intake for their operation, and are therefore capable of traveling beyond the atmosphere. A rocket engine carries with it all the materials required for its operation. These materials usually consist of a fuel and an oxidizer. The oxidizer is a substance capable of releasing all the oxygen required for burning the fuel.

Figure 2-38 charts the type of jet propulsion systems. Both types, rockets and atmospheric jets, receive their thrust as reaction to the exhaust of combustion gases. Jet engines frequently are called reaction motors, since the exhaust gases produce the action while the opposite motion of the missile or aircraft represents the reaction. Both types can be called thermal jets because they are dependent on the action of heat. The reaction which propels the jet engine occurs WITHIN the engine, and does not occur as a result of the exhaust gases pushing against the air.

ATMOSPHERIC JETS

Any jet-propelled system that obtains oxygen from the surrounding atmosphere to support the combustion of its fuel is an atmospheric jet engine. Pulsejets, ramjets, turbojets, and turboprops are all of this type, although the latter are not used in guided missiles. Obviously, the operation of these engines is limited by the amount of oxygen available, and they can operate only at altitudes where the oxygen content of the air is adequate. The

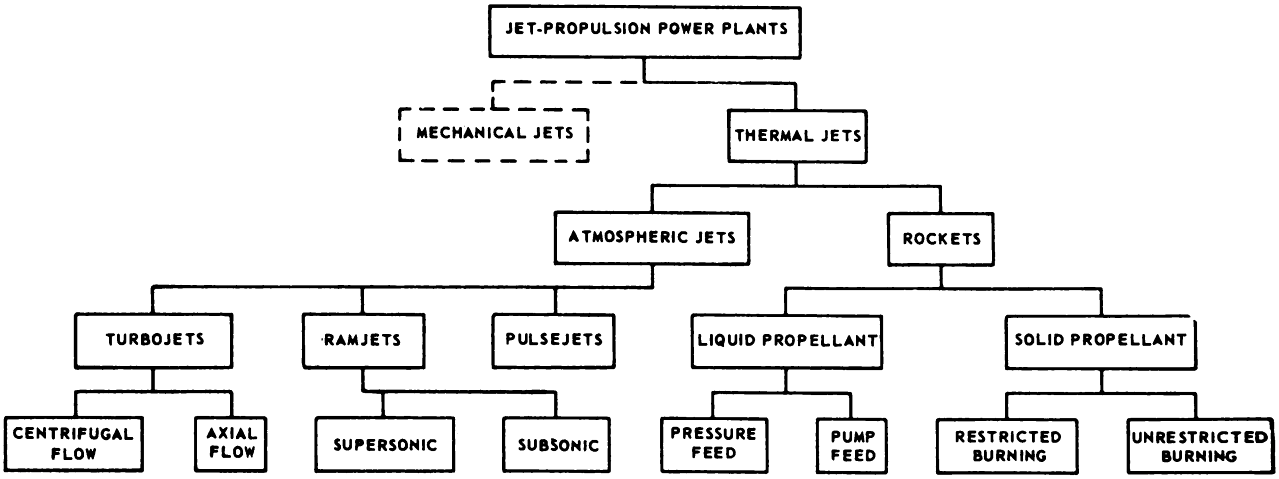

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Figure 2-38.—Classification of missile jet power plants.

upper limit of operation depends on the type of design of the particular engine.

Ramjet

A ramjet engine derives its name from the ram action that makes its operation possible. (This engine is sometimes referred to as the athodyd, meaning aerothermodynamic duct.) It is the simplest of the air-breathing propulsion engines, and has no moving parts.

Ramjet operation is limited to altitudes below about 90,000 feet because atmospheric oxygen is necessary for combustion. The velocity that can be attained by a ramjet engine is theoretically unlimited. The faster a ramjet travels the more effectively it operates, and the more thrust it develops. But its upper speed is limited, in practice, to about Mach 5.0, because of frictional heating of the missile skin. The major disadvantage of a ramjet is that the higher the speed at which it is designed to operate, the higher the speed to which it must be boosted before automatic operation can begin. The TALOS missile employs a ramjet propulsion system.

COMPONENTS OF RAMJETS.—Basically, a ramjet consists of a cylindrical tube open at both ends, with a fuel-injection system inside. From this, the term "flying stovepipe" originated. Even though all ramjets contain the same basic parts, the structure of these parts must be modified to produce satisfactory operation in the various speed ranges. The principal parts of a ramjet engine are a diffuser section; a combustion chamber that contains fuel injectors, spark plugs, and flameholder; and an exhaust nozzle (fig. 2-39).

The diffuser section serves the same purpose in the ramjet as it does in the pulsejet. It decreases the velocity and increases the pressure of the incoming air. Since there is no wall or closed grill in the front section of a ramjet, the pressure increase of the ram air must be great enough to prevent the escape of the combustion gases out the front of the engine. Diffusers must be especially designed for a specific entrance velocity, or predetermined missile speed. In other words, the desired pressure barrier is developed only when air is entering the diffuser at the speed for which that particular diffuser was designed.

The purpose of the air intake and diffusion system is to decelerate the velocity of the air from its free stream speed to the desired speed at the entrance of the combustion chamber with a minimum of pressure loss. Only air-breathing engines need diffusers.

The combustion chamber is of course the area in which burning occurs and high-pressure gases are generated. The fuel injectors are connected to a continuous-flow fuel supply system, adequately pressurized to permit fuel to flow against the high pressures that exist in the forward section of the combustion chamber.

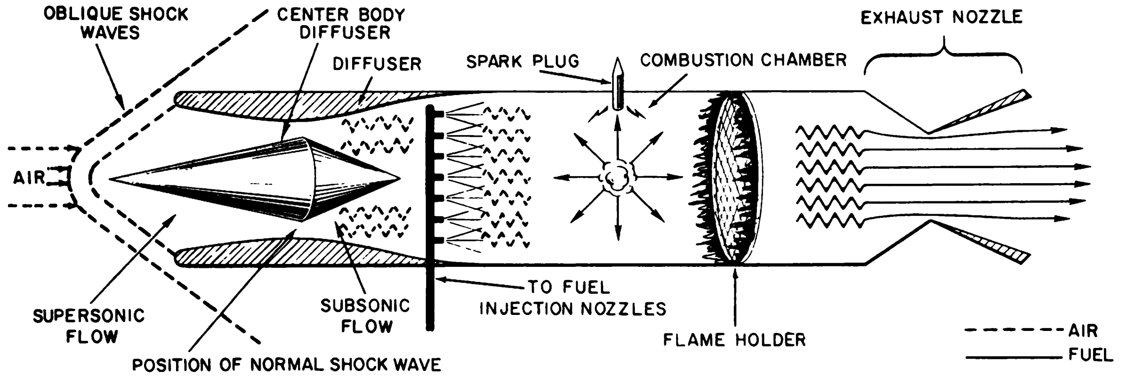

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Figure 2-39.—Supersonic ramjet operation.

Combustion is started by a spark plug; once started, it is continuous and self-supporting. The flameholder prevents the flame front from being swept too far toward the rear of the engine, thus stabilizing and restricting the actual burning to a limited area. The flameholder also ensures that the combustion-chamber temperature will remain high enough to support combustion.

A flameholder is a metal grid or shield punctured with a variety of sharp-edged holes (usually not round), designed to stabilize a flame. Burning propellants tend to linger in these holes and this ensures continuous ignition of the injected fuel throughout the operating cycle. Flameholders are necessary to prevent "blowout" of the burning fuel by the air rushing through the combustion chamber. The configuration and location of the flameholders is a crucial development problem in the ramjet. The flame speed varies with different fuels, but in general the flame speed is slower than the air speed through the combustion chamber. The flameholders reduce the local air speed to accommodate the slower flame speed.

The design and location of the fuel injection nozzles and the control system for fuel injection are important to get the correct proportion of air and fuel mixture in the combustion chamber.

The exhuast nozzle is a nonuniform chamber through which the gases generated in the combustion chamber flow to the outside. The function of the exhaust nozzle is to increase the velocity of the gases. Since the gases are allowed to escape out the rear through the exhaust nozzle, the force in the forward direction is unbalanced. The degree to which this force is unbalanced depends on the efficiency with which the exhaust nozzle can dispose of the rearward-moving combustion gases by converting their high-pressure energy into velocity energy.

OPERATION OF A RAMJET.—A supersonic ramjet engine cannot develop static thrust; therefore, it cannot take off under its own power. If fired at rest, high-pressure gases would escape out the front as well as the rear. For satisfactory operation, the engine must be boosted to a suitable supersonic speed so that the ram air entering the diffuser section developes a pressure barrier high enough to confine the escape of combustion gases to the rear only. Figure 2-39 is a diagram of a supersonic ramjet engine. Note the simple tubular construction, and the openings at front and rear.

As ram air passes through the diffuser the velocity of the air decreases while the pressure increases. This is brought about by the increase in cross section of the diffuser. Fuel is sprayed into the combustion chamber through the fuel injectors. The atomized fuel mixes with the incoming air, and the mixture is ignited by the spark plug. As previously stated, burning is continuous after initial ignition, and no further spark plug action is needed.

The gases that result from the combustion process expand in all directions, as shown by the arrows in the central part of the combustion chamber (fig. 2-39). As they expand in the forward direction, the gases are stopped by the barrier of high-pressure air and the internal sloping sides of the diffuser section. The only avenue of escape remaining for the combustion gases is through the exhaust nozzle, and here another important energy conversion occurs: The pressure energy of the combustion gases is converted to velocity. While the gases pass through the convergent nozzle, the pressure energy of the gases decreases and the velocity increases at the exhaust nozzle exit.

Thrust is developed in the ramjet as a result of the imbalance of forces acting in the forward and rearward directions. The bombardment of combustion gases against the sloping sides of the diffuser and the ram-air barrier exert a force in the forward direction. This forward force is not balanced by the combustion gases that escape through the exhaust nozzle. The unbalanced force constitutes the thrust that propels the missile.

ROCKET MOTORS

Unlike a jet engine, a rocket carries within itself all the mass and energy required for its operation. It is independent of the surrounding medium. In a rocket, the chemical reaction takes place at a very rapid rate. This results in higher temperatures, higher operating pressures, and higher thrust development than in jet engines. Because of the high pressures developed in rocket motors, the convergent-divergent nozzle is used so that more of the energy can be extracted from the gases after they have passed the throat section. The basic principles involved in the action of other jet-propulsion units also apply to rockets.

The TALOS Booster and the TERRIER, TARTAR, STANDARD, and SPARROW III missiles all utilize solid-fuel rocket motor propulsion systems.

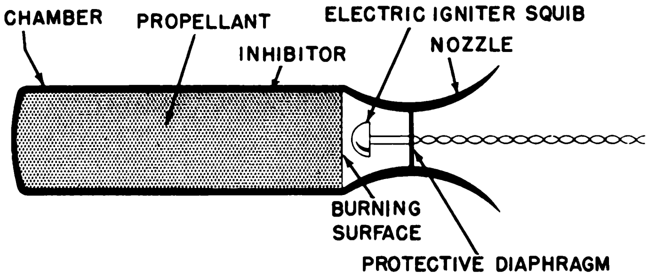

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Figure 2-40.—Components of a solid rocket motor, with end-burning grain.

A solid rocket unit consists of the pr pellant, combustion chamber, igniter, and e haust nozzle, figure 2-40.

The combustion chamber of a solid rocl serves two purposes. First, it acts as a sto age place for the propellant. Second, it serv as a chamber in which burning takes place. D pending on the grain configuration used, th chamber may also contain a device for holdi the grain in the desired position, a trap to pr vent flying particles of propellant from cloggi the throat section, and resonance rods to abso vibrations set up in the chamber.

The igniter consists of a small charge black powder, or some other material that c be easily ignited by either a spark dischar or a hot wire. As it burns, the igniter pr duces a temperature high enough to ignite t main propellant charge. Hollow cylindrical grai have inherently uniform burning rates. Furth configurations include end burning gra (fig. 2-40), internal burning star grain, and r and tube grain illustrated in figure 2-41.

Of the seven solid propulsion units us with the SMS missiles described in this ra training manual, the MK 30 shown in figure 2- is the only end-burner. All others burn radial outward with various internal geometric cavitie and have the igniter in the forward end.

The exhaust nozzle serves the same pu pose as in any other jet-propulsion system. must be of heavy construction and/or hea resistant materials, because of the high tempe atures of the exhaust jet.

The three missiles that employ the Sol Propulsion Unit with detachable boosters a TALOS, TERRIER, and STANDARD (ER). Th remaining three missiles, TARTAR, STANDAR (MR), and SPARROW are all Dual Thrust Rock Motors (DTRM) which have a booster gra cast within the sustainer grain, figure 2-4

The DTRM produces two levels of thrus During the first four seconds (approximate) o flight, the motor develops booster thrust su ficient to accelerate the missile to normal flig speed. After booster thrust ends, a slower burnin component in the rocket motor continues t develop a lower magnitude of thrust (sustaine thrust) to maintain normal flight speed. Because it develops both booster and sustaine

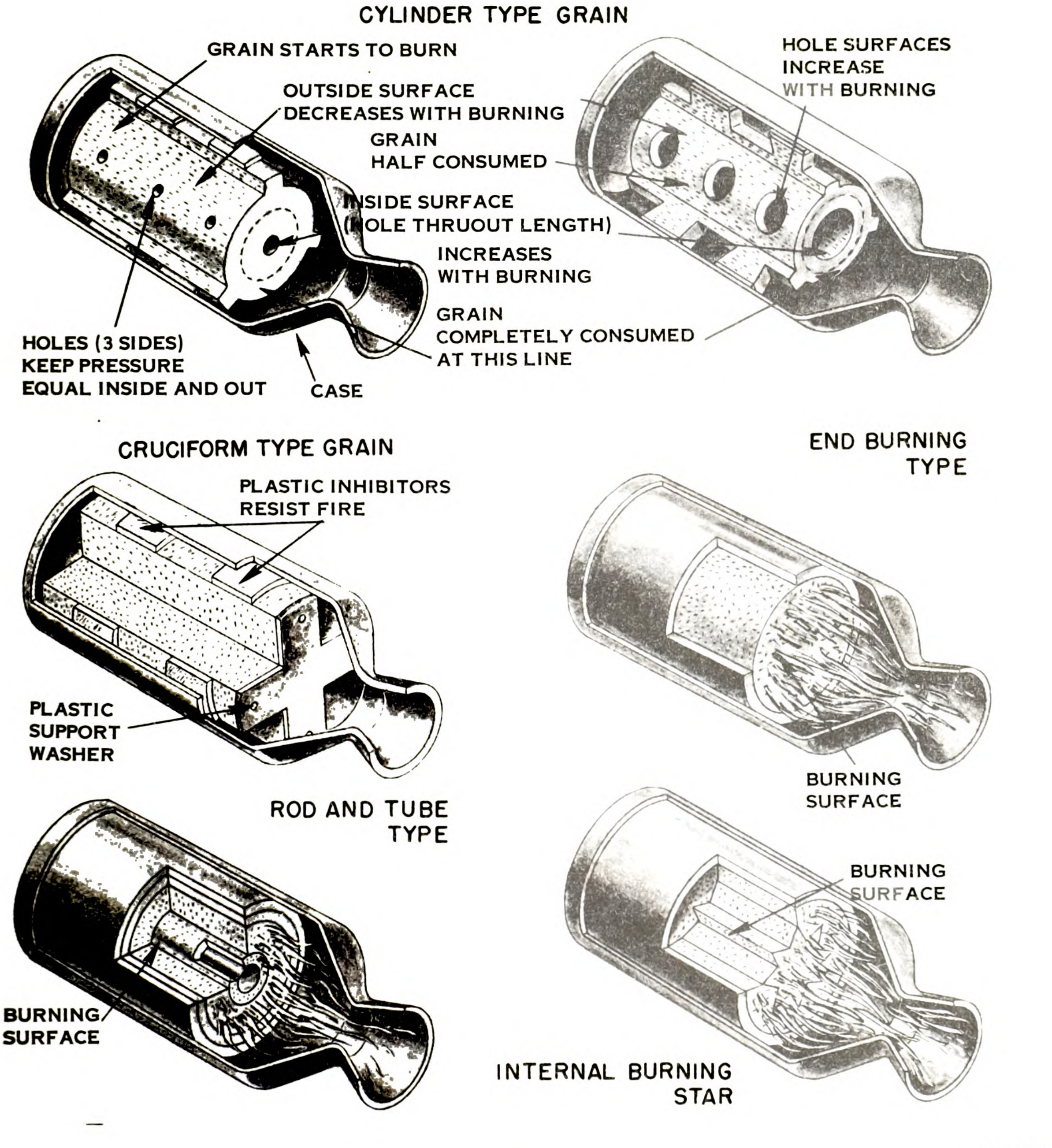
CYLINDER TYPE GRAIN
GRAIN STARTS TO BURN
OUTSIDE SURFACE DECREASES WITH BURNING
GRAIN HALF CONSUMED
INSIDE SURFACE (HOLE THRUOUT LENGTH) INCREASES WITH BURNING
GRAIN COMPLETELY CONSUMED AT THIS LINE
HOLE SURFACES INCREASE WITH BURNING
HOLES (3 SIDES) KEEP PRESSURE EQUAL INSIDE AND OUT
CASE
CRUCIFORM TYPE GRAIN
PLASTIC INHIBITORS RESIST FIRE
PLASTIC SUPPORT WASHER
END BURNING TYPE
BURNING SURFACE
ROD AND TUBE TYPE
BURNING SURFACE
BURNING SURFACE
INTERNAL BURNING STAR
167.708

Figure 2-41.—Solid propellant configuration.

thrust the motor is called a "dual thrust rocket motor" (DTRM).

Figure 2-43 shows a cross-section view of the DTRM as seen from the end of the missile. The inner, or booster part of the DTRM is a fast-burning type of propellant and burns first; and then the slower burning propellant in the sustainer portion takes over to furnish the thrust during the remainder of missile flight.

Operation of a solid rocket is simple. To start the combustion process, some form of electrically detonated squib is ordinarily used to

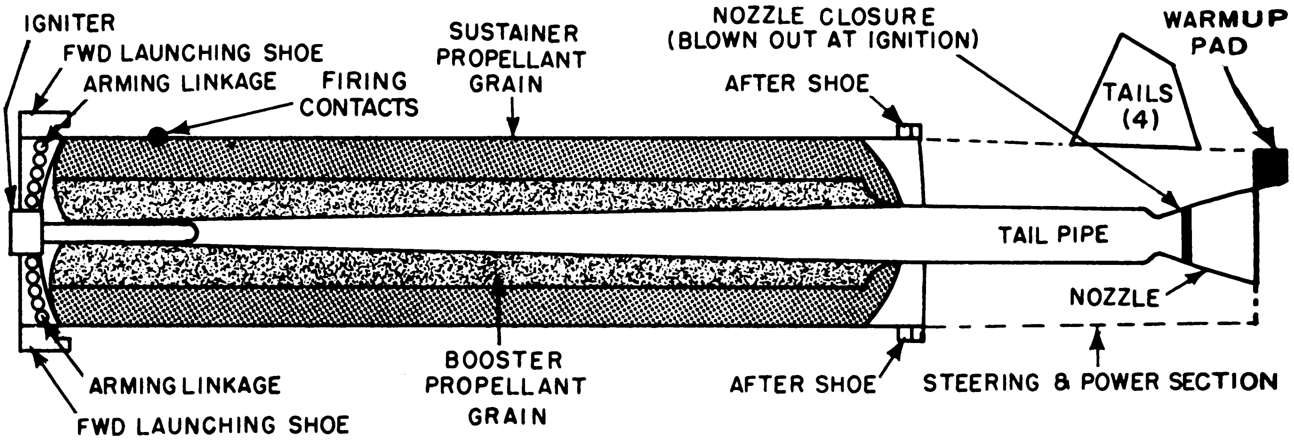

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Figure 2-42.—Cutaway view of a dual thrust rocket motor.

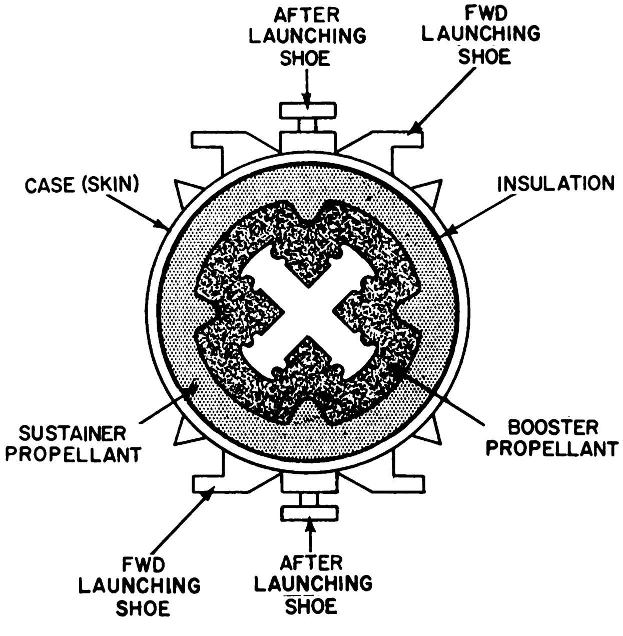

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Figure 2-43.—Cross section of DTRM, showing conformation of booster propellant and sustainer propellant grain.

ignite a smokeless or black powder charge. Upon igniting, the powder charge provides sufficient heat and the pressure to raise the exposed surface of the propellant grain to a point where combustion will take place.

MISSILE FLIGHT PATHS

A common way to bring a warhead and target together is to launch a missile at a target. This method has been used since men first started throwing rocks at one another. Now more sophisticated guided missiles, which travel farther and faster, and have tremendous destructive power are used.

A guided missile follows a path which is partially determined by the forces acting upon it. If these forces have been correctly predicted, the missile will hit the target.

FORCES EFFECTING FLIGHT PATHS

Some of the forces acting on a missile are due to nature; others are man-made. Natural forces include gravity, and those forces that are generated by the medium through which a missile is traveling (aerodynamic forces), which have been discussed in the missile structure part of this chapter. Natural forces are not fully controllable. Of course, their action on a missile can be modified by causing the missile to fly higher, reducing the aerodynamic and gravitational forces acting on it. Manmade forces include propulsion through jet thrust and rocket thrust, also steering forces.

NEWTON'S LAWS OF MOTION

Although Newton lived long before the missile and space age (1642-1727), the laws of motion which he discovered and formulated are valid for missiles and other objects passing through the atmosphere.

We discussed Newton's third law of motion during our study of propulsion. Now lets look at Newton's first and second laws of motion.

Newton's first law states: "A body in a state of rest remains at rest, and a body in motion remains in uniform motion, unless acted upon by some outside force." This means that if an object is in motion, it will continue in the direction and at the same speed until some unbalanced force is applied. And, whenever there are unbalanced forces acting on an object, that object must change its state of motion. In order to cause a body to deviate from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as INERTIA.

Newton's second law states: "The rate of change in momentum of an object is proportional to the force acting on the object, and in the direction of the force." The momentum of an object may be defined as the force that object would exert to resist any change of its motion.

ACCELERATION

Acceleration is a change in either speed or direction of motion. Thus, a missile accelerates as it increases or decreases speed along the line of flight, or if it changes direction in turns, dives, or pullouts, or as a result of a gust of wind. During accelerations a missile is subjected to large forces which tend to keep it flying along its original line of flight. This is in accordance with Newton's first law of motion which states: A body remains at rest or in a state of uniform motion in a straight line unless acted upon by an external force.

The force which acts on the missile during acceleration is measured in terms of the standard unit of gravity, abbreviated by the letter "g". A freely falling body is attracted to the earth by a force equal to its weight, with the result that it accelerates at a constant rate of approximately 32 feet per second per second. Its acceleration while in free fall is said to be one "g". Missiles making rapid turns or responding to large changes in thrust will experience accelerations many times that of gravity, the ratio being expressed as a number of "g's". The number of "g's" which a missile can withstand is one of the factors which determines its maximum turning rate and the type of launcher suitable for the weapon.

MACH NUMBERS AND SPEED REGIONS

Missile speeds are expressed in terms of MACH NUMBERS rather than in miles per hour or knots. The Mach number is the ratio of missile speed to the local speed of sound. For example, if a missile is flying at a speed equal to one-half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2. (The term "Mach number" is derived from the name of an Austrian physicist, Ernst Mach, who was a pioneer in the field of aerodynamics.)

Local Speed of Sound

The speed expressed by the Mach number is not a fixed or constant quantity since the speed of sound in air varies directly with the square root of the absolute temperature of the air. For example, it decreases from 760 miles per hour (mph) at sea level (for an average day when the air is 59° F) to 661 mph at the top of the troposphere. The speed of sound remains constant (with the temperature) between 35,000 feet and 105,000 feet, then rises to 838 mph, reverses, and falls to 693 mph at the top of the stratosphere. Thus you can see that the speed of sound will vary with locality.

The range of aircraft and missile speed is divided into four regions which are defined with respect to the local speed of sound. These regions are as follows:

SUBSONIC FLIGHT.—In which the airflow over all missile surfaces is less than the speed of sound. The subsonic division starts at Mach 0 and extends to about Mach 0.75. (The upper limit varies with different aircraft, depending on the design of the airfoils.)

TRANSONIC FLIGHT.—In which the airflow over the surfaces is mixed, being less than sonic speed in some areas and greater than sonic speed in others. The limits of this region are not sharply defined but are approximately Mach 0.75 to Mach 1.2.

SUPERSONIC FLIGHT.—In which the airflow over all surfaces is at speeds greater than sound velocity. This region extends from about Mach 1.2 upward.

HYPERSONIC FLIGHT.—In which the time of passage of the missile is of the order of

RELAXATION TIME. Relaxation time is the time required for molecules of air to adjust themselves to the presence of a body or to readjust themselves after the passage of the body. Mach numbers on the order of 10 may be considered as hypersonic. Velocities that are not hypersonic at sea level may become so at high altitudes, since relaxation times will be longer where densities are relatively low.

Subsonic Flight

At subsonic speeds, sustained flight is dependent on forces produced by the motion of the aerodynamic surfaces through the air. If the surfaces of airfoils are well designed, the streams of air flowing over, under, and around them are smooth, conforming to the shapes of the airfoils. If, in addition, the airfoils are set to the proper angle and if motion is fast enough, the airflow will support the weight of the aircraft or missile.

Transonic and Supersonic Flight

Control of missiles in the transonic and supersonic regions differs somewhat from that at subsonic speeds. Particularly in the transonic regions are the effects varied, depending mainly on the characteristics of the missile involved. The differences in control may be the result of COMPRESSIBILITY, a property of the airstream which is not prominent at low speed but which cannot be ignored at high speeds.

THE NATURE OF COMPRESSIBILITY.— When an object moves through the air, it continuously produces small pressure disturbances in the airstream as it collides with the air particles in its path. Each such disturbance — a small variation in the pressure of the air — is transmitted outward in the form of a weak pressure wave. Each expanding pressure wave travels at the speed of sound. Although each pressure wave expands equally in all directions, the important direction is that in which the object generating it is moving.

As long as the missile is moving at low subsonic speeds the pressure waves, traveling at the speed of sound, move out and away from the missile. Therefore, when the missile arrives at any given point, the air particles agitated by the pressure wave are already in motion and can easily and smoothly flow around it. But, when the missile approaches the speed of sound, the pressure waves are generated almost as fast as they can move away from the missile. This means that the greater the speed of the missile, the fewer the number of air particles that will be able to move from its path, with result that the air begins to pile up in front of the missile. In other words, more air is compressed in the area just ahead of the missile.

When the missile reaches the speed of sound, it is moving at the same speed as the pressure waves it generates. Thus a situation occurs in which the air particles forward of the compressed region at one moment are completely undisturbed, and at the next moment are compelled to undergo drastic changes in velocity, density, temperature, and pressure. Because of the sudden nature of the transition, the boundary between the undisturbed air and the compressed region is called a SHOCK WAVE.

Shock Waves

There are several types of shock waves, the principal classes being the NORMAL and the OBLIQUE (fig. 2-44). These differ primarily in the way in which the airstream passes through them. In the normal (or perpendicular) wave,

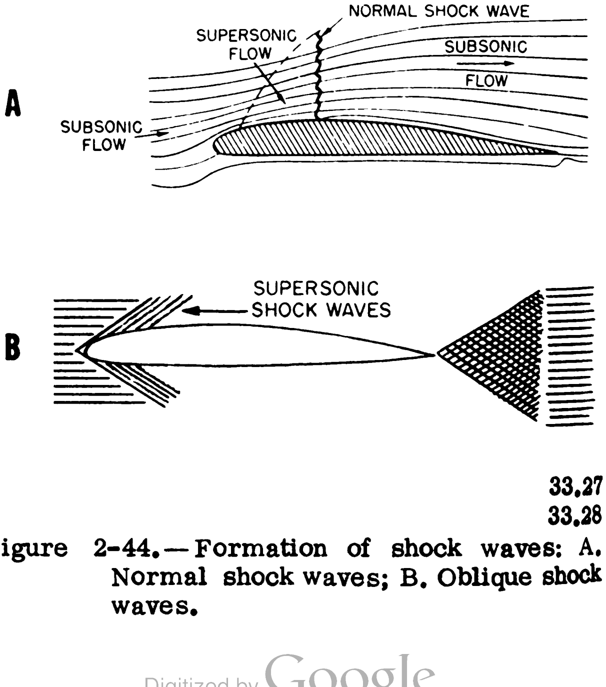

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Figure 2-44.—Formation of shock waves: A. Normal shock waves; B. Oblique shock waves.

the air passes through without changing direction, and the wavefront is perpendicular to the line of flow. The normal shock wave is usually very strong; that is, the changes in pressure, density, and temperature within it are great. The air passing through the normal shock wave always changes from supersonic to subsonic velocity.

Oblique shock waves are those in which the airstream changes in direction upon passing through the transition marked by the wavefront. These waves are produced in supersonic airstreams at the point of entry of wedgeshaped and other sharply pointed bodies. The resulting wavefronts make angles of less than 90° with the line of flight. Like the normal shock wave, the oblique wave occurs at a point of change in velocity from a higher to a lower value. The change in speed is usually from supersonic to subsonic but not always so. In some cases the airflow is supersonic both upstream and downstream of the oblique wave. In general, the variations in density, pressure, and temperature are less severe in the oblique wave than in the normal shock wave.

FLIGHT PATH PHASES

A missile in flight does not necessarily experience the same type of force all the time. During some portions of its flight it may travel through air in which the density varies according to altitude.

A guided missile generally experiences natural and man-made forces, with velocity vector control, throughout its flight.

In any missile flight, those phases during which there is no velocity vector control (boost phase) acting on the missile are called phases of ballistic flight. In missile flight, those phases during which there is velocity vector control acting on the missile are called phases of guided flight.

Man-made forces include thrust and directional control as shown in figure 2-45. The vector sum of all the forces, nature and man-made, acting on a missile at any instant, may be called the total force vector. It is this vector, considered as a function of time in magnitude and direction, which provides velocity vector control.

GUIDED FLIGHT PATHS

A variable guided missile path is one that can be changed during flight, either by orders from the launching ship (beam riding), or in response to new target data received by the missile. When a missile path is determined by

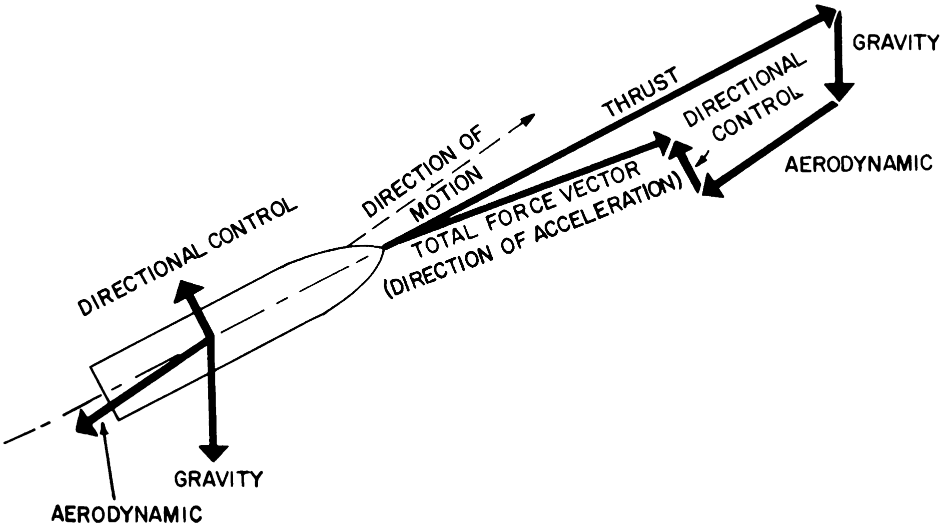

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Figure 2-45.—Vector control.

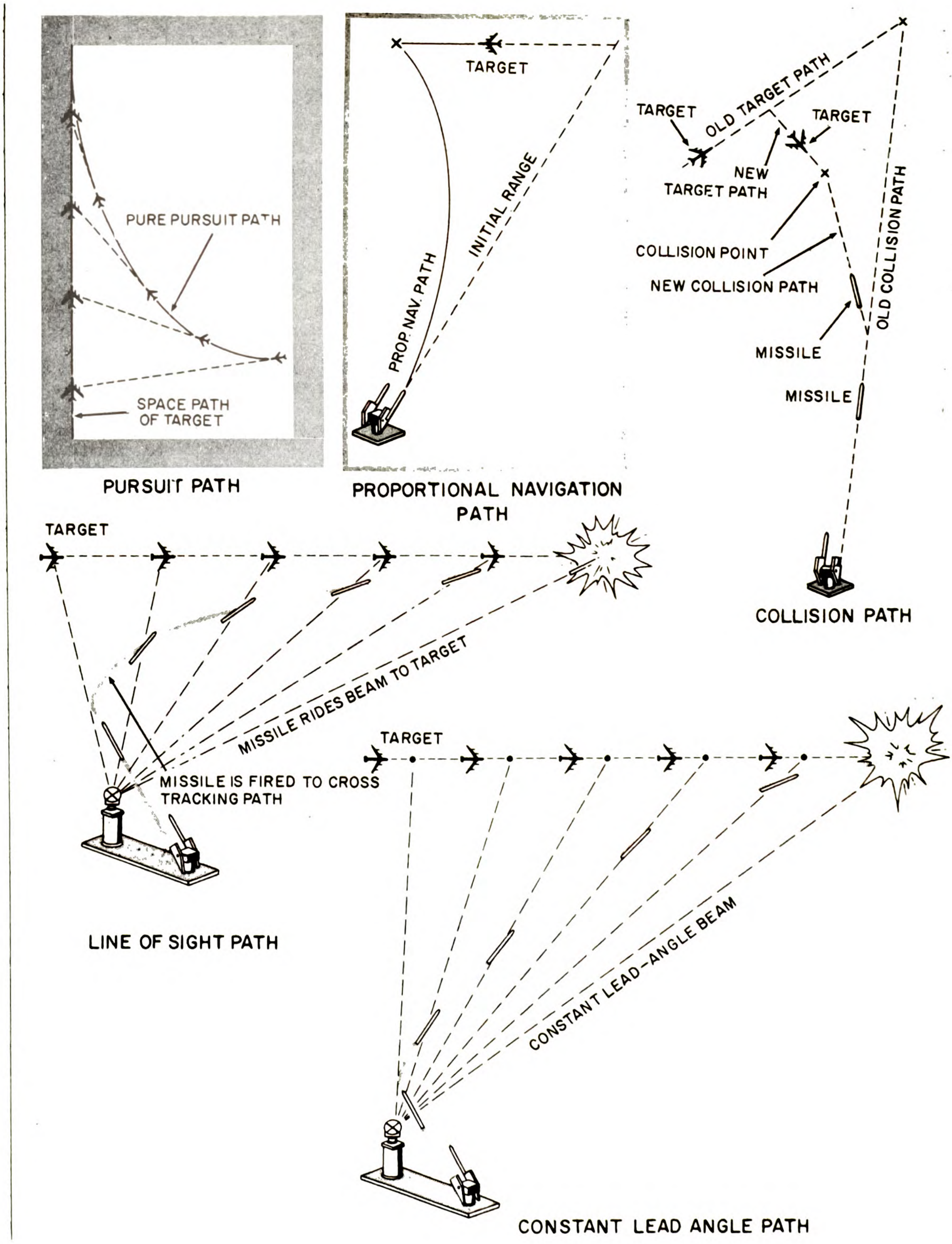

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Figure 2-46.—Types of guidance paths.

target data received directly from the target by the missile, the missile is said to be "homing". By convention, homing is divided into three categories, as discussed previously in this chapter:

(1) Active. The missile transmits energy to the target and guides itself by the echo signal received.

(2) Semi-active. The target receives energy from the launching ship. The missile picks up the echo signal and guides itself by the signals received.

(3) Passive. The target receives no transmitted energy. The missile guides itself by radiation (heat, infrared, or electronic countermeasure signals) emitted from the target.

Types of Paths

PURSUIT.—The simplest procedure for a guided missile to follow is to remain pointed at the target at all times. The missile is then headed along the line of sight at every instant and its track describes a Pursuit path. The rate of turn of the missile is always equal to the rate of turn of the line of sight. Pursuit paths are highly curved near the end of flight, Figure 2-46.

COLLISION.—At the opposite extreme to a pursuit path is a Collision path. The missile is aimed at such a point ahead of the target that both the missile and the target will reach that point at the same instant. The line of sight does not rotate relative to the missile. The missile path is as linear as a path can be when the missile is acted on by gravity and air resistance. If the target makes an evasive turn, a missile executing a variable collision path will compute a new collision point from the new target path, and will aim at that point.

PROPORTIONAL NAVIGATION.—A missile may also fly a path which is intermediate between a pursuit path and a collision path. This is known as a Proportional Navigation path. The missile travels in such a way that its own rate of turn is proportional to the rate of turn of the line of sight from missile to target at any instant. If the missile rate of turn equals the line of sight rate of turn, the flight path becomes a pursuit path (which is really a special case of the proportional navigation path). In general, in proportional navigation, the missile rate of turn is a fixed multiple of the line of sight rate of turn. Proportional navigation paths are less curved than pursuit paths, but more curved than collision paths.

LINE OF SIGHT.—Another path that can be flown by missiles is the Line of Sight path. Here, the missile is guided so that it always travels along the line of sight from launching ship to target. This is an example of "beam riding", where the missile rides a beam that is radiated from the ship and kept trained on the target. Note that a pursuit path also follows a line of sight, the line of sight from the missile. A beam-riding line of sight path follows the line of sight from the launching ship.

CONSTANT LEAD ANGLE.—An alternative form of beam riding path is the Constant Lead Angle path; here the beam is kept ahead of the line of sight by a constant offset.

CHAPTER 3

WEAPON CONTROL SYSTEMS

A weapon control system is the nerve center of a complete weapons system, and has as its elemental purpose the control of a guided missile to ensure the maximum kill probability of the weapon system. The various functions of the control system may be categorized as (1) to receive and assimilate tracking information from system radar equipment regarding location, velocity, and attitude of a target, or targets, (2) to calculate or compute the predicted line of fire to ensure capture of beam riding missiles by the guidance beam, (3) to position the missile launcher in accordance with its computed launcher orders, and (4) to control the guided missile flight path after launch to ensure target intercept.

FUNCTIONS OF THE SYSTEM

The principal subsystems of a weapon control system are the data gathering elements; the data processing, data conversion, and coordinate conversion devices utilized in the fire control computer to calculate the predicted launch angle; and the missile flight path control devices (guidance) that effectively control the flight orientation of the missile on order from the fire control computer prior to launch; and during flight time for beam riding missiles.

DATA GATHERING

The gathering of data for use as input to the fire control prediction unit of the computer is called DATA GATHERING and is one of the prime functions of a weapon control system. The data must contain sufficient information to allow the computer unit to do more than make an educated guess in its determination of a predicted launch angle.

DATA PROCESSING

Once this required data is gathered, it then becomes necessary to compute the predicted launch angle within a predetermined length of time so that the missile may be launched with the proper velocity vector to ensure a hit, or guidance beam capture of the missile. Computation of the predicted launch angle is the basic requirement of DATA PROCESSING, a second prime function of a weapon control system.

DATA CONVERSION

During the operation of DATA GATHERING and DATA PROCESSING, it may be necessary to convert data from one reference frame to another or from a particular coordinate system within a reference frame to a second coordinate system. For instance, target data obtained during tracking may be measured in the horizontal plane, and environmental data obtained may be measured in a stable earth plane. If the computation used by the computer is in the horizontal plane, the environmental data must undergo a process called DATA CONVERSION so that this data becomes equivalent to data measured in the horizontal plane. The definition of reference frames will be discussed later in this chapter.

COORDINATE CONVERSION

If the target data is measured in spherical (polar) coordinates, but the computation is determined by rectangular (cartesian) coordinates, then the spherical coordinate data must be transformed into rectangular coordinate data within the stabilized deck reference frame so that the computer may operate properly. This process is called COORDINATE CONVERSION.

The fire control computer produces the predicted launch angle as one of its outputs. What remains is for the computer to position the missile launcher so that the missile line of fire (launch) is offset from the target tracking line of sight by an angle equal to the prediction launch angle. In order for this to be accomplished, orders must be sent to the launcher directing it to a position coincident to the computed missile line of fire (launch) position. However, it must be remembered that the reference plane of the launcher may not be the same as the one utilized at the computer. For example, a guided missile launcher on a cruiser is referenced in the deck plane. Launcher orders from the computer must then take into account pitch and roll. In other words, a further DATA CONVERSION process which transforms the launcher orders from a stabilized to an unstabilized reference plane is required.

MISSILE LAUNCHING CONTROL

When the launcher is assigned to the fire control system, the mode of the system is automatically selected to coincide with the missile type on the launcher rails. This selection enables the computer to generate proper launcher orders. Some missile orders are supplied while the missile is on the launcher and some also via a guidance transmitter to the in-flight missile.

FIRE CONTROL PROBLEM

The fire control problem may be stated as follows: How must a missile be fired at a target (stationary or moving) from a ship (stationary or moving) to obtain a hit on the target? In order to accomplish the problem's solution, we have to have effective control of our missile. A successful solution of the missile fire control problem provides us with this control.

The definition of fire control states that fire control is the technique of delivering effective fire so as to damage or destroy a selected target. Since there is one basic fire control problem, it is logical to assume that many fundamental elements are common to all the variations of the problem. The word element as used here refers to a basic quantity or factor. Therefore much of the material in this chapter is common to each surface missile system of the Navy. Some of these common elements are:

1. A line of sight which is an imaginary line from your ship to the target's present position.
2. Prediction quantities which will be used to predict target's future position.
3. A line of fire which is an imaginary line along which the missile will be launched.

How these elements of the problem are acquired will become obvious as we proceed through this chapter.

Our basic problem can be divided into six fundamental sequential operations: DETECTION, ACQUISITION AND TRACKING, PREDICTION, LAUNCHER POSITIONING, GUIDANCE, and EVALUATION (intercept). Figure 3-1 illustrates the fire control problem sequence. The 3-T problems (including the Standard missile) can be broken down to the same six operational phases. Once again the difference lies in the solution technique. The Basic Point Defense fire control problem is similar to the 3-T problems; however, the Point Defense fire control system is somewhat different as you will see illustrated later in this chapter.

TARGET DATA

The first fundamental and necessary step in the problem's solution is the gathering of all relative information on the problem. One of the most critical pieces of information that must be determined is that a target exists. This requires the use of some form of detection system. In today's Navy this is accomplished by the search radar system which permits operation at extreme distances, in darkness, and during all types of weather.

Having detected a target, precise positional information is required. This information can be provided by the same source which detected the target. Many devices, however, are incapable of providing both the detection facilities and the precise data required on specific targets. In these cases, a second radar system is provided to track specific targets. This positional information determines the line of sight to the target.

Not only is the present position of the target required, but its velocity (course and speed) must be ascertained.

ANCILLARY DATA

Information other than target data is often equally important for missile flight path (trajectory) determination. Ballistic corrections require such environmental data as gravitational force components, wind velocity, and own ship movement for precise calculations. The course and speed of the launching ship, and its stabilization characteristics if not correctly integrated into the computations, can cause severe deviation in missile interception trajectory. Information on factors other than target data is

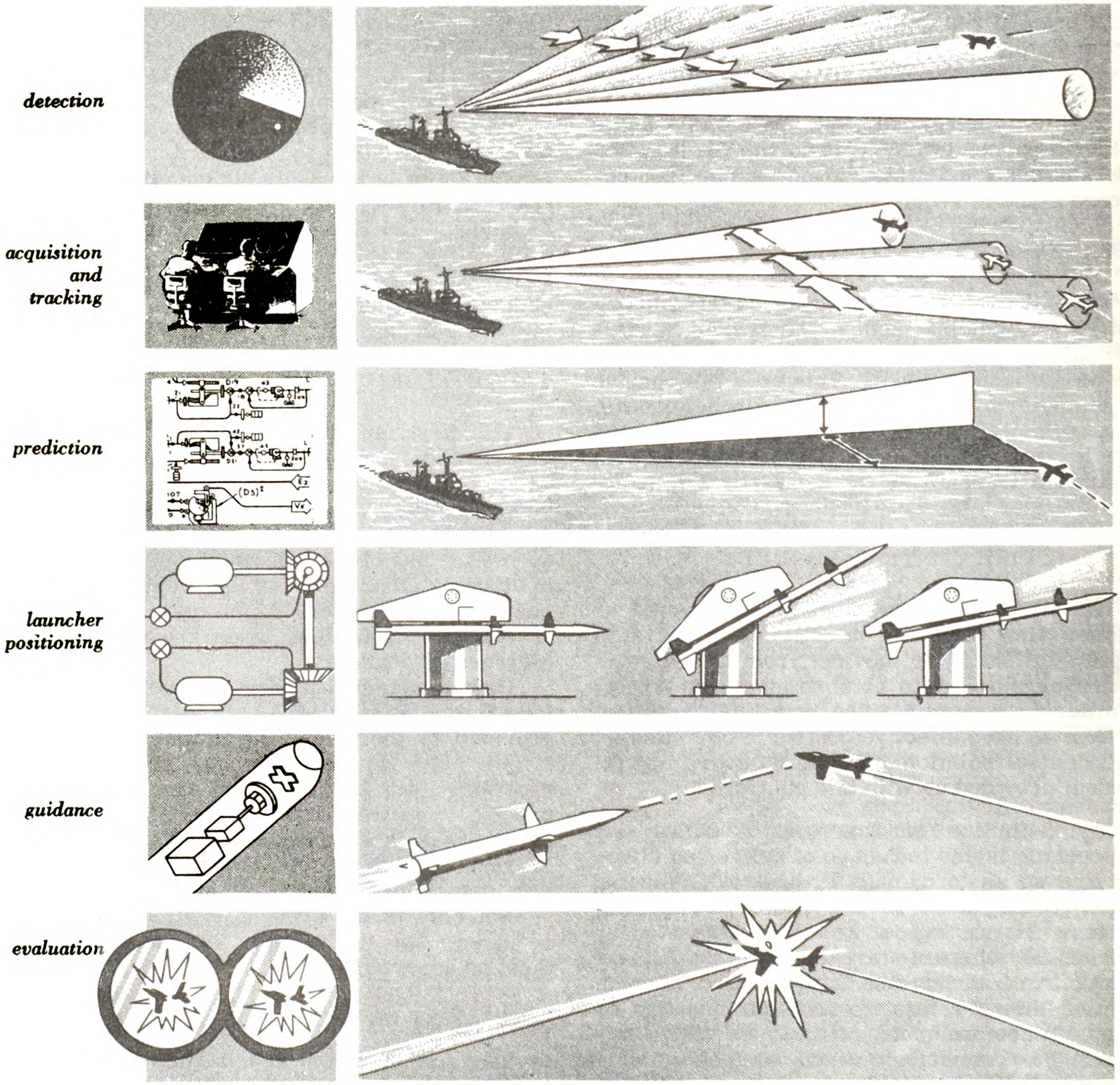

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Figure 3-1.—Fire control problem sequence.

often called ancillary or auxilary data and is of extreme importance to correct computation of interception flight paths.

USABLE DATA

All this information or data will be transmitted to the fire control computer. Usually this data cannot be used directly in computations. Some data will be received continuously, and other data may be received only intermittently. Certain data will be erratic, and fluctuations will occur in the quantity being measured. Some measurements may be taken at one spot, while others may be taken in another part of the ship. Because of these and other problems, the raw data must be processed to arrive at a unified set of usable data.

With usable data, the necessary calculations must be performed to determine the launch position angle and the missile's flight path trajectory. This calculation process is done by complex digital or analog computing devices. These computers simply may perform certain operations to aid the Fire Control Technician, or (normally) they may be set up to perform all the necessary calculations when the required data is provided to them.

FIRE CONTROL SUBSYSTEMS

The fire control problem then is reduced to three separate operations listed below and illustrated in figure 3-2:

TRACKING
COMPUTATION
POSITIONING

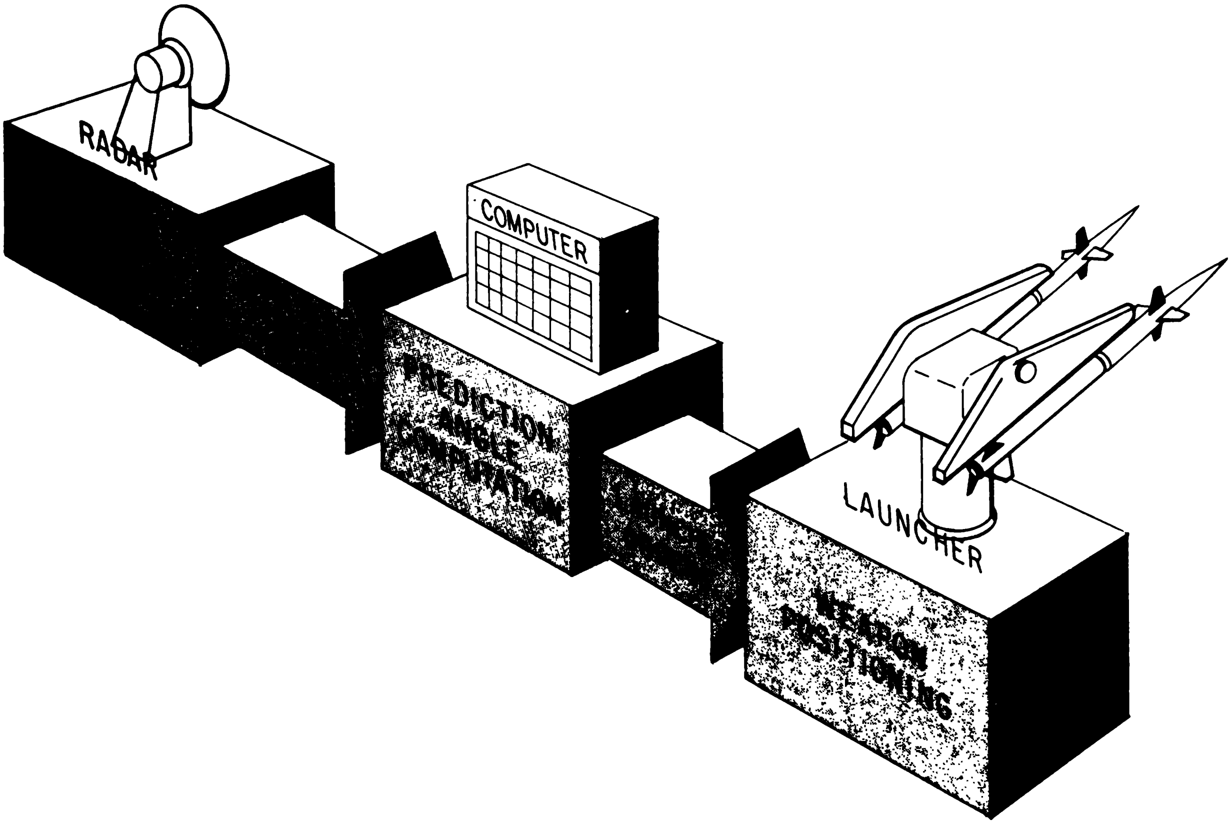

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Figure 3-2.—Fire control operation.

Detection and Tracking

The first operation, performed by the detection and tracking subsystem, detects the target and provides all necessary data on the target. The fire control radar performs this function by establishing a tracking line of sight (LOS) along which it receives the returned or reflected energy from the target. Since the speed of light is about 186,000 miles per second, and the target ranges involved are relatively small, the time for light energy, or radio frequency (RF) energy, to travel to and from the target can be considered instantaneous, and the radar indications of the target can be considered the present target positions.

Computation

The second operation of the fire control problem that must be performed is the computation of the missile launcher positioning angle and the guided missile flight path trajectory. This operation consists of two parts. The data which is received is processed into a usable form, and then the arithmetic operations are performed. This operation is performed by the computer.

Launcher Positioning

The third operation that must be performed is the positioning of the launcher in accordance with the calculated prediction angle. This amounts to offsetting the launcher axis from the LOS by the amount of the prediction angle, or total lead angle, by means of the launcher drive mechanism. During in-flight guidance, a guidance beam operates to reposition the beam-rider missile during its flight, and radar reflections from the target operate to reposition the homing missile during its flight.

Before we pursue the subject of fire control systems any further, let us first relate the information just discussed to a fundamental antiaircraft fire control problem using a beam-rider missile.

The Beam-Rider Missile AA Fire Control Problem

After the search radar has located the attacking aircraft, the fire control tracking and guidance radar follows the aircraft with its RF energy beam. In some guided missile fire control systems, such as Talos, the target tracking beam follows the target; while the guidance beam is programed by the fire control computer to a missile-target intercept point in space. After the boost phase of flight, the booster case drops off and the sustainer ignites. The missile then follows or "rides" the beam to the target.

Before the missile can follow the guidance beam (a narrow long range beam), it must come within the area of the capture beam (a wide short range beam). The missile is captured by the capture beam and manuvered to the center of the guidance beam. The guidance beam takes over to manuver the missile all the way to the target. In figure 3-3A you see that the "aiming point" crosses the beam. Corrections for the effects of missile trajectory (air density, gravity, wind) will deflect the trajectory so the missile enters the capture beam and comes under its control.

The fire control missile computer continuously figures out where the capture beam and the capture point are. The computer determines the launcher train and elevation orders based on beam position, target motion, and ballistic factors. These orders are electrical signals which position the launcher. The missile is fired and if the lead angle is accurate, the missile hits the capture point and is captured by the beam. Once the beam has control of the missile, the missile rides the guidance beam until it intercepts the target (fig. 3-4).

While figure 3-4 shows the missile flying straight to the target, in actual practice this is far from the case. The target is moving rapidly; the radar beam follows it, and the missile follows the beam. The target may change its course, and this may mean sharp changes in the course of the radar beam and the missile that rides it. A missile is subject to the same forces as a gun projectile while in flight. Corrections to the trajectory are calculated before the missile is fired, so it will have a correct start on its flight.

Lead angle is made up of two corrections—lead due to target motion, and lead due to ballistics. Assume that lead because of target motion is correct. If the missile is launched on a line pointed directly at the capture point, the missile will miss the capture point. Why? Because ballistic corrections have not been added to launcher train and elevation orders. These ballistic factors are (1) parallax, (2) gravity, and (3) wind deflection.

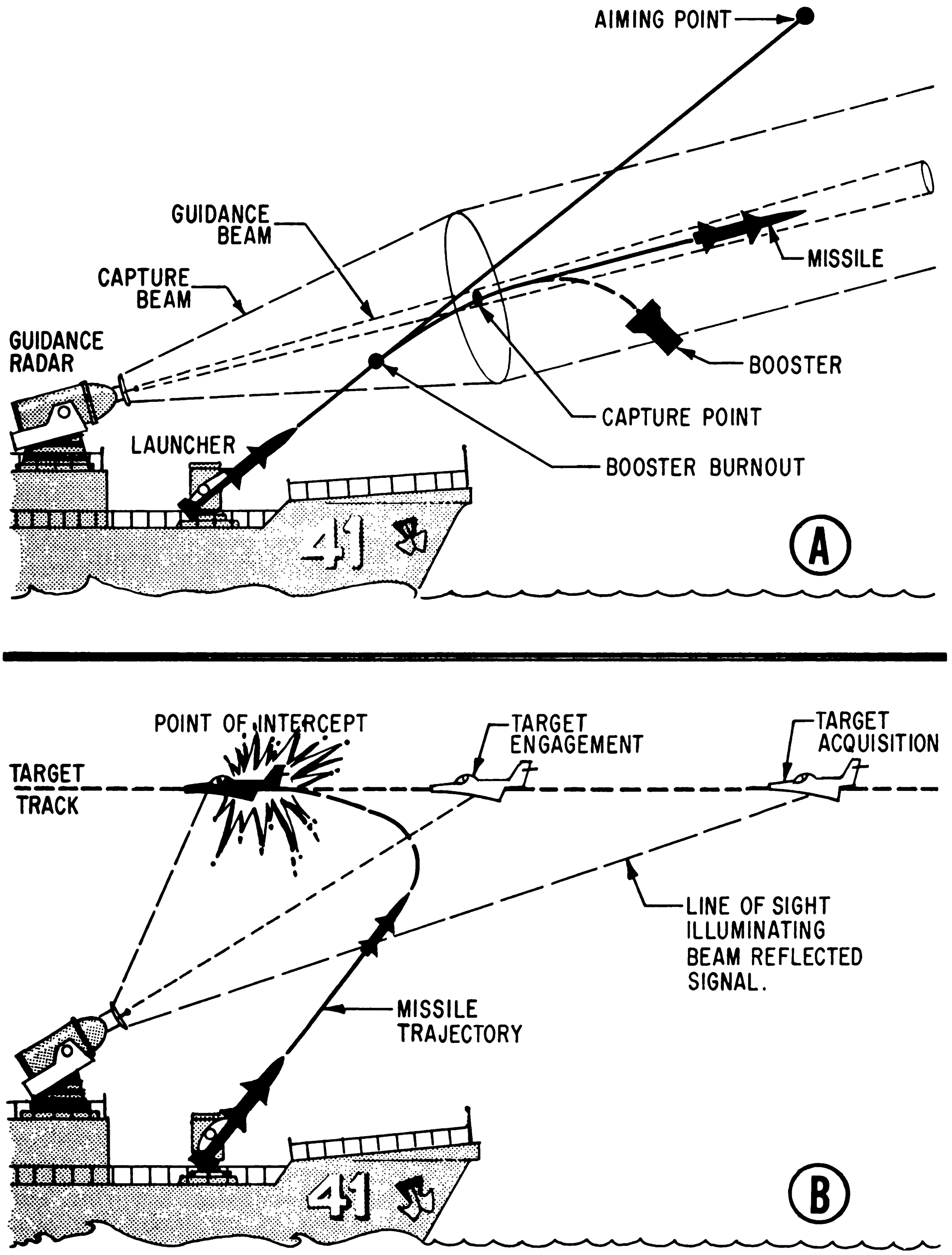

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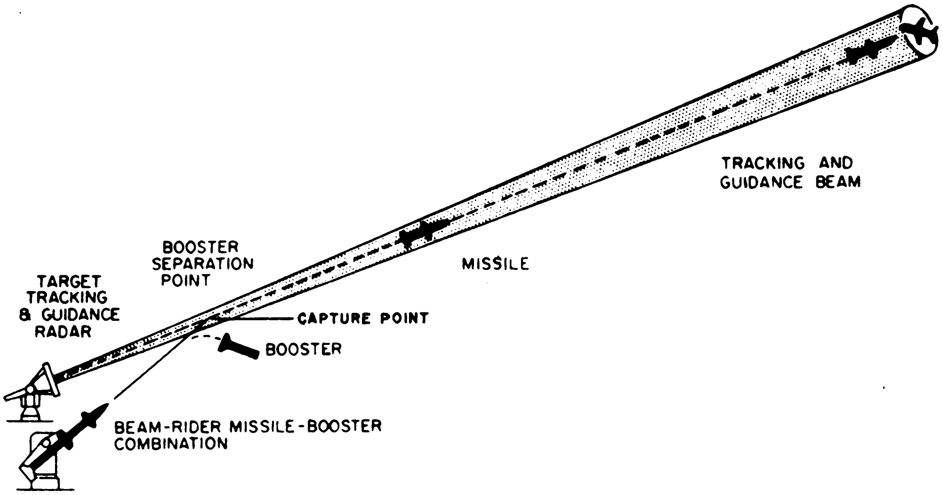
Figure 3-3.—Simplified fire control problem: A. Beam-rider capture phase; B. Basic Point Defense.


TRACKING AND GUIDANCE BEAM
MISSILE
BOOSTER SEPARATION POINT
TARGET TRACKING & GUIDANCE RADAR
CAPTURE POINT
BOOSTER
BEAM-RIDER MISSILE-BOOSTER COMBINATION

12.32

Figure 3-4.—Beam-rider missile follows the radar beam to the target.

Basic Point Defense Fire Control Problem

The Basic Point Defense fire control problem, figure 3-3B, depicts the geometry for tracking an approaching airborne target and the missile trajectory to target intercept. The missile line of fire coincides with the guided missile director line of sight in bearing, but is 10 degrees above the director in elevation (to provide an up-and-over trajectory of the missile to the target). The missile employs semiactive homing guidance to seek the intercept point by receiving RF energy which is radiated from the director and by receiving reflected RF energy from the target.

Target designation data signals conveying bearing and elevation coordinates are transmitted to the director, where they provide the director operator with visual target indications for target detection and acquisition.

Visual target indications are used in detecting, acquiring (lock on), and tracking the target. The director radiates RF energy transmitted from the radar transmitter, receives RF energy reflected from the target, and provides modulation (coding) signals to the transmitter. The transmitter provides rear reference signals to the missile, allowing the missile receiver to tune to the fire control system frequency. When the radar locks on an approaching target, lock stability, target velocity, altitude, and range are displayed at the fire control panel. Director bearing (target bearing during track) is also displayed at the fire control panel.

The missile receives orders in the form of prelaunch data from the fire control system and guided missile launching system. The prelaunch data are simulated Doppler, sweep select, head aim, and English bias.

Simulated Doppler is transmitted to the missile, providing simulated target Doppler and positioning the missile speedgate so that actual target lock on can occur in minimum time after enable.

Sweep select is transmitted to the missile, positioning the missile speedgate in long sweep or short sweep. Prior to enable and target lock on, long sweep is selected; after enable and target lock on, short sweep is selected.

Head aim and English bias are transmitted to the missile, to establish an up-and-over trajectory.

During the identifying, acquiring, and initial tracking phases of the target, the launcher is ready for assignment. Due to the erractic movement of the director, the launcher is not assigned to the fire control system during target search and acquisition; the launcher remains in the electrical stow position. When the launcher is assigned, position signals from the director are transmitted to the guided missile launching system, synchronizing the launcher with the director position.

When the missile receiver has tuned to the fire control system frequency and the missile speedgate has locked on the simulated Doppler, the missile is ready to fire.

The final function to be performed prior to missile launch is the enabling of the missile. The fire control system launch zone computer receives target data from the director and computes this data to determine when a target is within a possible high kill area. The fire control panel operator enables the firing circuit and fires the missile. The missile in flight will search for the radar signal and home on the target (which is illuminated by RF energy from the fire control system) to target destruction.

MISS PRODUCING EFFECTS

Many factors serve to complicate the fire control problem. Among them are the inherent unpredictability of the motion of any specific target and the inaccuracies possible in the missile flight path because of variations in the launcher and propulsion systems and to external causes such as gravity, wind, and drag.

Parallax

Guided missile fire control equipment is spread out over the ship, the launcher and the guidance radar are physically offset along the centerline of the ship and also are at different heights above the deck of the ship. Therefore, if the launcher and radar are positioned at the same bearing and elevation angles, the line of fire of the launcher will be parallel to the guidance beam. As you know, the amount these parallel lines are offset from each other is called parallax. To compensate for parallax, the launcher bearing and elevation angles are offset toward the guidance beam. The launcher line of fire intersects the guidance beam, and the missile trajectory will intersect the capture point. Time to beam capture is very short, about 5 seconds after launch; booster burnout occurs about 1 second before this.

Figure 3-5 shows what happens if the missile's trajectory is not corrected for parallax. The missile trajectory and guidance beam are offset, and the trajectory does not intercept the capture point. If we launched a missile under these conditions, the result would be a missile "by the deep-six".

Gravity

In figure 3-6, you can see the effect of gravity on the missile's trajectory. For clarity, we have neglected the parallax and wind effects. Between launch and capture, gravity acts on the missile. At the instant when the missile should be captured by the guidance beam, it is actually some distance below the capture point. To compensate for the gravity effect, the launcher must be elevated so that the launcher line of fire intersects a point above the capture point. This technique used to compensate for the effect of gravity is called superelevation correction.

Wind

Figure 3-7 illustrates the effects of wind on the missile trajectory. Once again, other effects are ignored. The wind tends to blow the missile off course during the period between launch and capture. Since the missile is not guided during this portion of its flight, wind corrections must be made before launch. The fire control computer calculates these corrections and sends them to the launcher. Therefore, the launcher is offset from the guidance radar line of sight by an amount proportional to the speed of the wind, and in a direction opposite to that of the wind. Now the wind will blow the missile into the guidance beam at the capture point.

The correction for wind includes not only true wind (atmospheric) speed and direction, but also apparent wind, caused by the ship's movement.

REFERENCE FRAMES

Usually, telling where something is located presents us with no particular problem. From early childhood we have all become accustomed to answering "where" questions, and in ordinary circumstances, we find little difficulty in giving information that is good enough for the purpose.

But there's a big difference between telling Aunt Minnie where to find her cat and giving the kind of position information necessary to pinpoint and destroy an enemy aircraft in our atmosphere. In fire control, the problem of exact definition of position is of prime importance.

To better understand the description of reference frames, we will first take a look at the symbols used to describe fire control quantities necessary to solve the fire control problem.

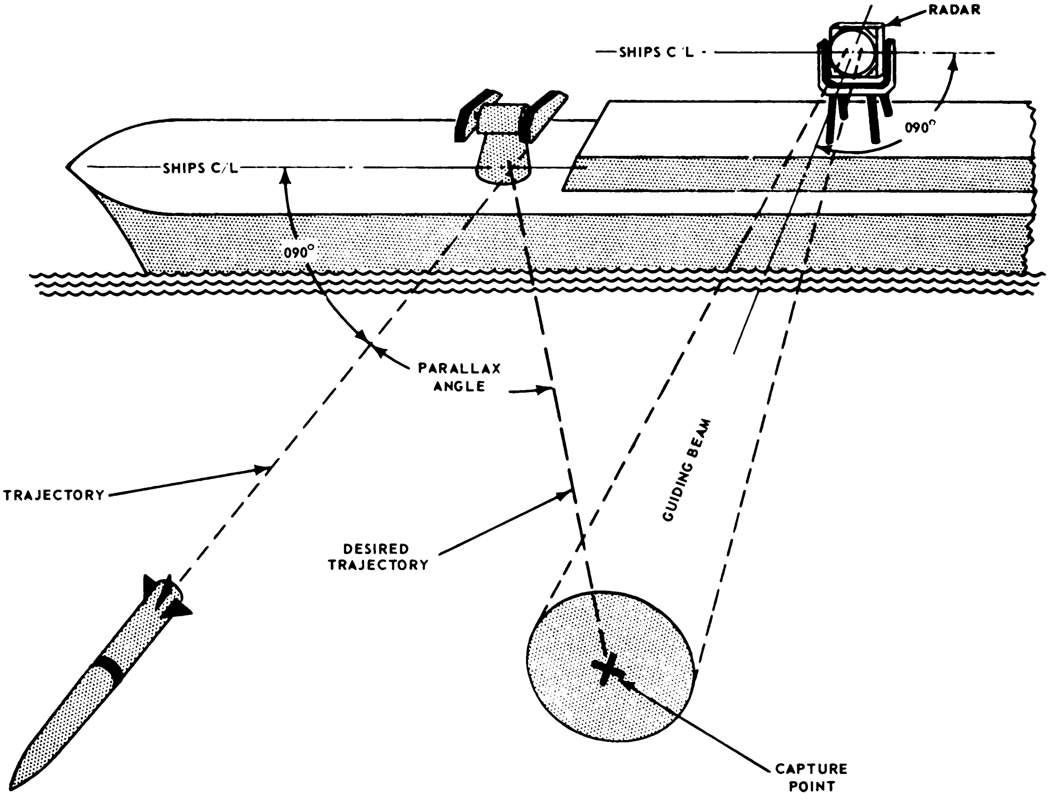


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Figure 3-5.—Effect of parallax on a guided missile's trajectory (flight path) during boost.

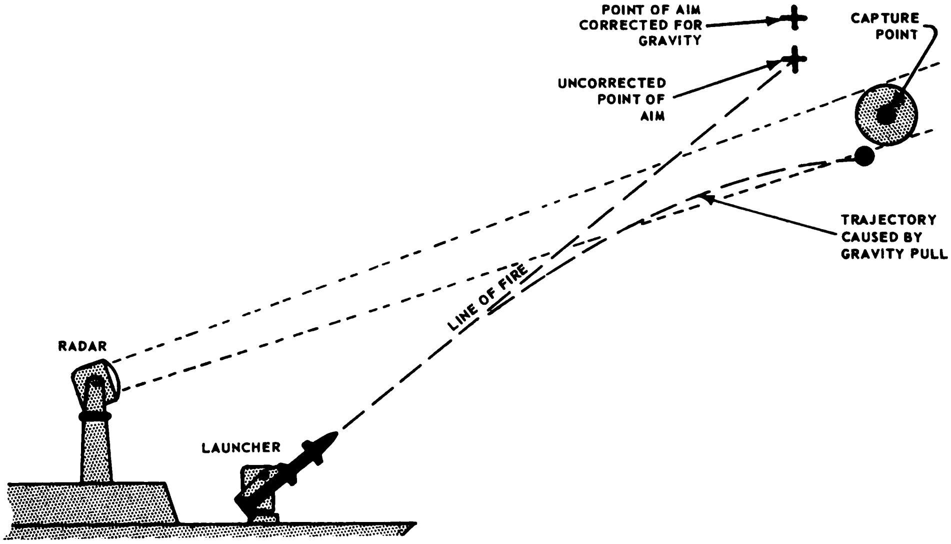

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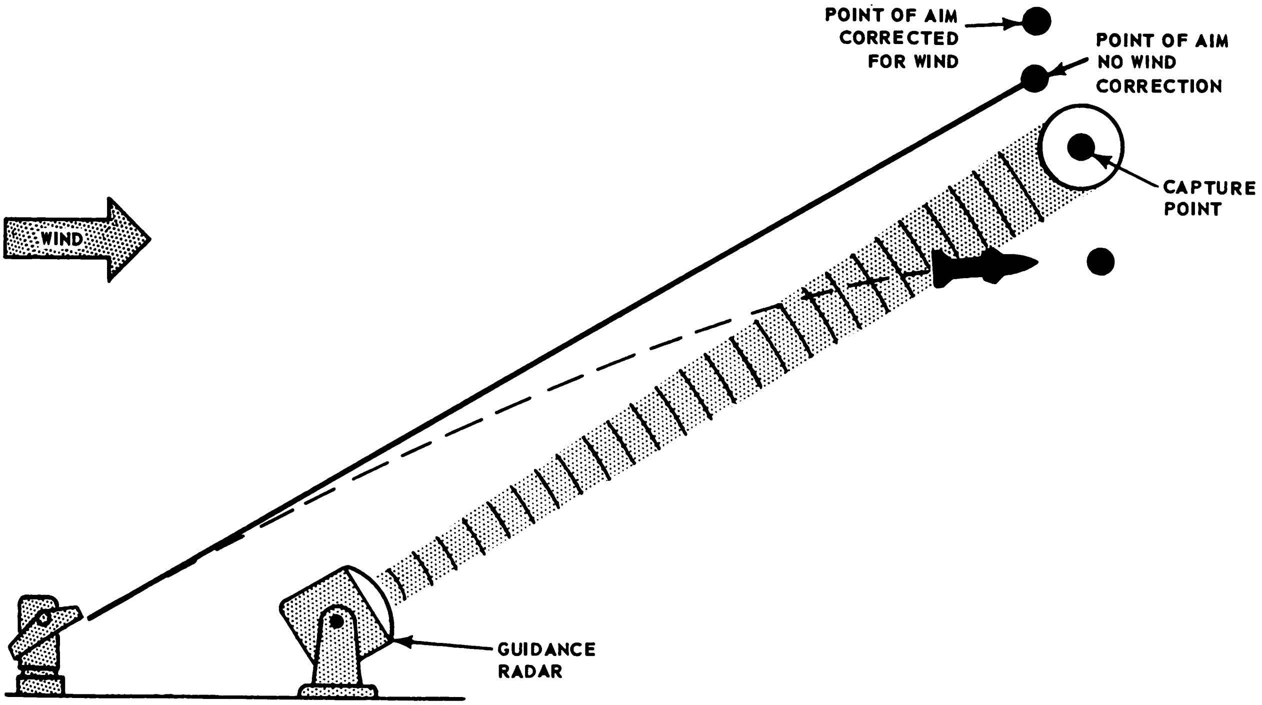
Figure 3-6.—The effect of gravity on a missile's flight path during the boost phase.


POINT OF AIM CORRECTED FOR WIND
POINT OF AIM NO WIND CORRECTION
CAPTURE POINT
WIND
GUIDANCE RADAR

83.9

Figure 3-7.—Effect of wind on a missile's flight path.

Standard Fire Control Symbols

The fire control symbol system establishes a uniform pattern for all quantities used in surface, antiaircraft, and underwater fire control problems. This includes gun, missile, and underwater weapons found aboard ship. Symbols are not new to you; mathematics, electricity, and electronics use them extensively. The need for symbols is obvious. Symbols are concise, specific without ambiguity, and easily recognized and understood. The problem will be expressed in symbols, for they are the language of the Fire Control Technician.

A description of the symbol system will not be covered in this course, but the basic symbols and their modifiers are listed. The fire control symbols are made up of these basic symbols and their modifiers. The symbols define the quantities they represent. The fire control symbols, their construction and definitions are covered in OP 1700, Volumes 1 and 3.

In the present system of fire control symbols, all common features of the problem are divided into classes of quantities, (such as bearing, elevation, and range). We can rigidly define a quantity by:

1. Class.
2. Where it is measured (such as in the deck plane, future position, relative or true, LOS, or LOF).
3. How it is measured (such as linear or angular rate).

The result of this approach is a uniform, flexible system. This symbol system can be applied to all quantities in any method of solution to the fire control problem.

Basic Symbols and Modifiers

The basic symbols assigned to represent the basic geometrical quantity in each class, and the letters and numerals used to modify these basic symbols are shown in table 3-1.

Quantity Modifiers

Besides the geometrical quantities in each class, the portions of these quantities measured

Table 3-1.—Basic symbols and modifiers

BASIC SYMBOLS

Symbol	Name
A	
B	Bearing of LOS *
Bm	Bearing of LSM * *
mB	Bearing of LMT +
C	Course of target from own ship
Cm	Course of missile from own ship
mC	Course of target from missile
D	Rate of
E	Elevation of LOS
Em	Elevation of LSM
mE	Elevation of LMT
Ei	Level from LOS
Eim	Level from LSM

BASIC SYMBOL MODIFIERS

Modifier	Name
a	Apparent or athwarthship
b	Bearing
c	Computed
d	Deck
e	Elevation
f	Flight
g	Launcher
h	Horizontal
i	
j	
k	Earth
l	
m	Missile
n	Nutational
o	Own ship
p	Prediction
q	Heading
r	Range
s	Line of sight

167.161

Table 3-1.—Basic symbols and modifiers—Continued

BASIC SYMBOLS		BASIC SYMBOL MODIFIERS	
Symbol	**Name**	**Modifier**	**Name**
mEi	Level from LMT	**t**	Target
F	Missile offset angle	**u**	
G	Gyro angle	**v**	Vertical
mG	Crossing angle	**w**	Wind
H		**x**	East-West
I	Angle of inclination	**y**	North-South
mI	Angle of missile inclination.	**z**	Cross level
K	Arbitrary constant	**'**	Prime
L	Sight deflection from LOS	**''**	Double Prime
Lm	Sight deflection from LSM.	**1**	Order
M	Linear movement	**2**	Future position
mM	Relative guidance displacement.	**3**	Launching Position
P	Launcher parallax base length.	**4**	Aiming position
Pm	Guidance radar parallax base length.	**5**	Fuze
Ps	Tracking radar parallax base length.	**6**	Capture position
Q	Radar phasing order	**(())**	Double parentheses

Table 3-1.—Basic symbols and modifiers—Continued

BASIC SYMBOLS	
Symbol	**Name**
R	Range along LOS
Rm	Range along LSM
mR	Range along LMT
S	
T	Time
U	Speed
V	Sight angle from LOS
Vm	Sight angle from LSM
W	Wind rate
Z	Cross level about LOS
Zm	Cross level about LSM
mZ	Cross level about LMT

* LINE OF SIGHT (SHIP TO TARGET)
** LINE OF SIGHT (SHIP TO MISSILE)
+ LINE OF SIGHT (MISSILE TO TARGET)

to various positions and accounting for various affects are symbolized. Also, in the expression of rates, the frame of measurement of the rate is indicated. These quantity modifiers (table 3-2) are applied by enclosing the symbols for the geometrical quantities in parentheses and preceding or following the parentheses with the quantity modifiers. In general, when the modifier precedes the parentheses, it defines the correction to the basic quantity due to the effects of the modifier. If the modifier follows the parentheses, it defines the basic quantity corrected for the effects of the modifier.

Symbol Construction

A few examples of symbol construction will give us a better understanding of how the system works.

Example 1

D = Rate of
M = Linear movement
b = bearing
DMb = Rate of linear movement in bearing

Example 2

B = Bearing
y = North/south
By = True bearing (measured to north/south axis)

Example 3

R = Range
h = horizontal
x = East/west
Rhx = Horizontal range along an east/west axis.

Target's Present Position

A target's position can only be described by relating it to a known reference point, for position is a relative quantity. We describe a location by measuring its direction and distance from a point known to us. (Try to describe any location, say the director or plotting room, without a known starting or reference point.)

The need for a reference or starting point to describe target's position is obvious. It can also be seen that a system of measuring direction and distance from that reference point is needed. The reference point is contained in a frame of reference. The systems of measuring from the reference point are called "coordinate" systems.

Table 3-2.—Quantity modifiers

QUANTITY MODIFIERS			
Modifier	**Name**	**Modifier**	**Name**
a		o	Observed or measured
b	Ballistic	p	Launcher parallax
c	Computed, generated, or smoothed	pm	Guidance beam parallax
d	Designated	ps	Tracking director parallax
e	Error	q	Corrective input, spot, or bias
f	Function	r	Rotational
g	Dead time	s	Selected
h	Missile	t	Translational
i	Increment	u	Unclear
j	Computational addition or partial	v	
k	Earth	w	Wind
l	Initial	x	
m	Relative motion	y	
mg	Crossing angle	z	
n			

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Frame of Reference

A frame of reference is a system of lines, angles, and planes within which we can measure a target's present position. Each frame of reference has a point from which all measurements are made. This point is called the reference point or the origin. A baseball field can serve to show what we mean by frame of reference. The playing field is established from home plate by the foul lines. The game takes place within these lines. All measurements are made from home plate, the reference point. The importance of the location of the reference point is apparent, since everything is related to it.

There are four frames of reference used in naval fire control. Each is determined by the method used to establish the reference point. The reference point is normally located within own ship or the destructive package. (Examples of the term "destructive package" as used here are missile and torpedo.) The advantage in this location is that all measurements are therefore made with respect to own ship or the missile.

The four frames of reference are coordinate systems rigidly attached to (1) own ship, (2) the earth, (3) the missile, or (4) inertial space. A fire control system may use any one of these frames, or possibly a combination of them. The frame being used can be recognized by the reference point's location and how it was established.

The frame of reference, RIGIDLY ATTACHED TO OWN SHIP, has a reference point which is built into the weapon system. The system is unstabilized. All measurements of target's present position are made from the reference point located in the deck plane. The deck plane moves in all directions with own ship.

The EARTH frame of reference is considered attached to the surface of the earth and rotates with the earth. The reference point is contained in the horizontal plane, which is independent of ship's roll and pitch. The horizontal plane is established by a gravity-seeking device (stable element) within own ship or the missile. The fire control systems using this frame of reference can be either fully or partially stabilized.

In a system fully stabilized all measurements of the target's position are made with respect to the horizontal and vertical planes. In a partially stabilized system only a section of the system is stabilized. The stabilized section, normally the computer, measures target's position with respect to the horizontal and vertical planes. In the other sections of the weapon system (director, weapon launcher) the reference point, located in the deck plane, moves with the ship in all directions. Each of the 3-T missile fire control systems is an example of a partially stabilized system.

The frame of reference, RIGIDLY ATTACHED TO THE MISSILE, has a reference point built into, and moving with, the missile. The missile's reference planes containing the reference point are orientated to own ship's reference planes when the source of guidance is located in own ship. When the source of guidance is contained in the missile, its reference planes are oriented to the earth or to an inertial space frame. Missile and torpedo systems, for example, may use this frame of reference.

The INERTIAL SPACE frame of reference is considered independent of earth's motion and to have a constant velocity with respect to a "fixed star"—for example, Polaris. The reference point is considered to be at the center of the earth and therefore nonrotating. This reference point can be established aboard ship or in the missile if an inertial device (such as a free gyro) is used. The inertial space reference is used when the time of flight is long and the effects of earth's rotation must be considered.

The earth frame can be considered inertial for short times of flight, since the error caused by earth's rotation is so small it can be ignored.

As a FTM, you will be primarily concerned with the first three frames of reference.

COORDINATE SYSTEMS

The target's present position is located in a frame of reference by a coordinate system. The coordinate system measures the target's distance and direction from the reference point. A coordinate system gives a graphic representation of the target's present position.

We can define a coordinate here as a number representing the length of a line that has a known direction relative to a reference axis. To locate a point in a plane requires two coordinates. Each coordinate represents a dimension. As an example, own ship's location can be determined by the coordinates of latitude and longitude (fig. 3-8). It would follow then that a surface target's location from own ship can be determined by two dimensions. In this case both own ship and the target are in the same plane.

There are two basic coordinate systems used to locate a point in a plane: (1) the rectangular

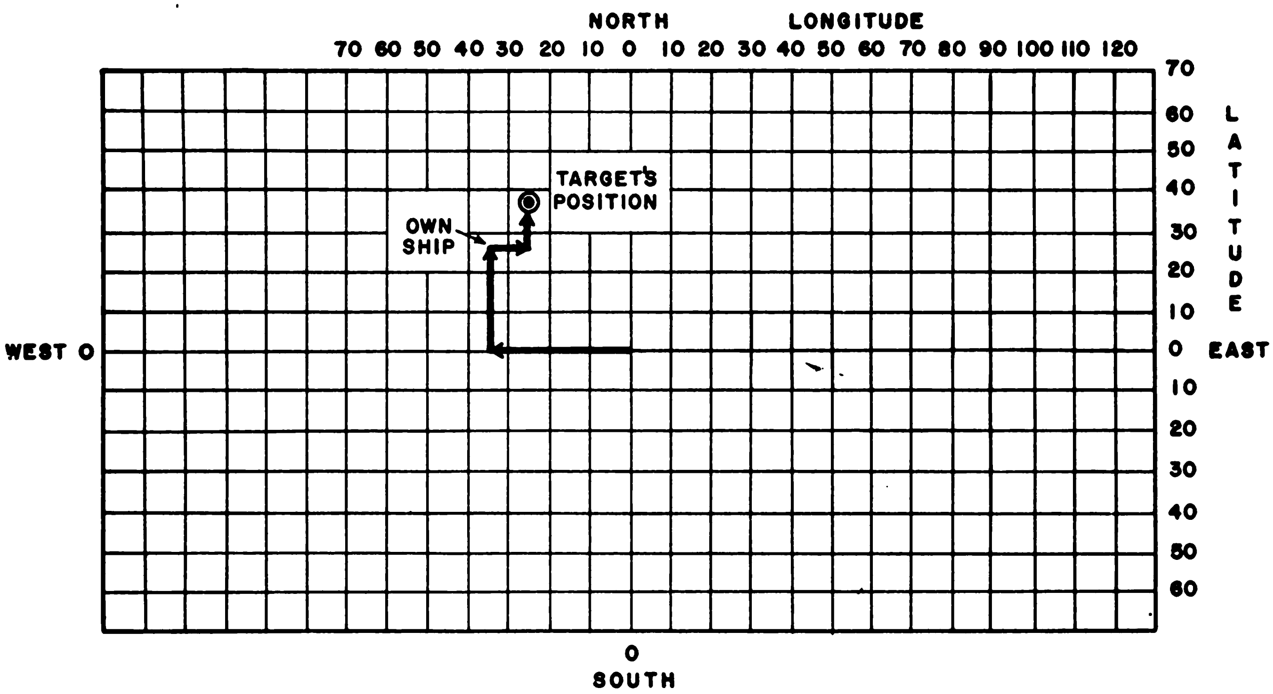

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Figure 3-8.—Earth's coordinates (latitude and longitude).

or Cartesian coordinate system, which uses two linear coordinates; and (2) the polar coordinate system which uses one angular and one linear coordinate.

Rectangular Coordinate System

The rectangular coordinate system uses a frame of reference similar to that shown in figure 3-9. The two lines, X and Y, intersect at right angles. The horizontal line is usually labeled X and called the X axis. The vertical line is usually labeled Y and called the Y axis. The point where the X and Y axes intersect is called the origin, and labeled with the letter O. The origin is, of course, our old friend, the reference point.

The origin is the starting point for measuring along both axes. To the right of the origin, numbers on the X axis are positive and to the left they are negative. The numbers along the Y axis above the origin are positive; below the origin they are negative.

A point anywhere in the plane of the graph may be located by two numbers. One number shows the distance of the point from the origin along the X axis. The other number shows the

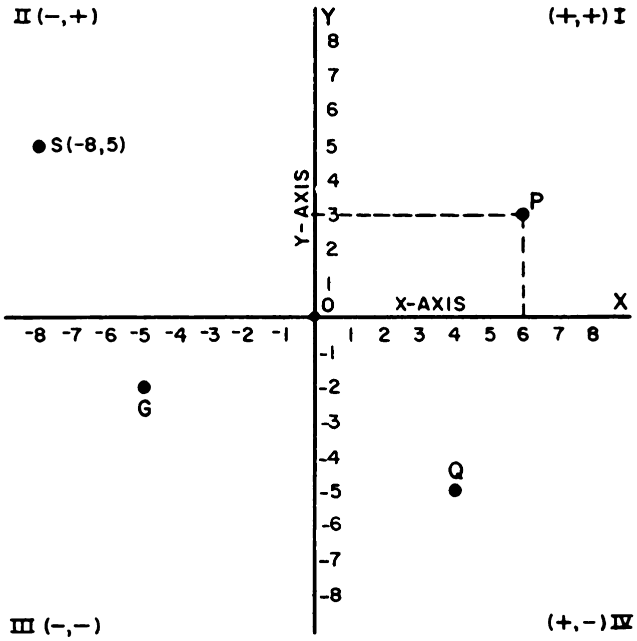

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Figure 3-9.—Rectangular coordinate system.

distance of the point from the origin along the Y axis. Thus, point P in figure 3-9 is 6 units to the right of the origin along the X axis and 3 units above the origin along the Y axis. When we write the coordinates, the X coordinate is always written first. The coordinates for point P would be written: P(6,3).

QUADRANTS.—The X and Y axis divide the graph into four parts called quadrants. In figure 3-9, point P is in the first quadrant; point S is in the second quadrant; point G is in the third quadrant; and point Q is in the fourth quadrant. In the first and fourth quadrants, the X coordinate is positive, because it is to the right of the origin. In the second and third quadrants, the X coordinate is negative, because it is to the left of the origin. The Y coordinate is positive in the first and second quadrants, being above the origin, and negative in the third and fourth quadrants, being below the origin. The signs of the coordinates in the quadrants are shown in the figure.

Locating points with respect to axes is called "plotting the points." As shown with point P (fig. 3-9), plotting a point is equivalent to completing a rectangle. This is the reason for the name rectangular coordinate system.

Polar Coordinate System

The polar coordinate system is developed on a frame of reference similar to the rectangular coordinate system. The two lines, X and Y (fig. 3-10) intersect at right angles. The origin, labeled with the letter O, is at the point of intersection. The origin is the axis, or pole, around which the angular coordinate revolves.

A point anywhere in the plane of the graph can be located with two coordinates. The linear coordinate is the distance of the point from the origin. This distance is called the radius and is usually symbolized by the letter r. Since r denotes distance (range) and not direction, it is always positive.

Normally, the angular coordinate is measured from the X axis to the right of the origin. The angle increases as it is rotated counterclockwise. In fire control, however, we know that the angle (bearing) is measured from the Y axis. Also the angle increases as it is rotated in a clockwise direction. This is done for convenience, and, conventionally, bearing is measured clockwise. The principles of the polar coordinate system remain the same. We simply have reversed the direction of rotation and shifted the axis 90 degrees.

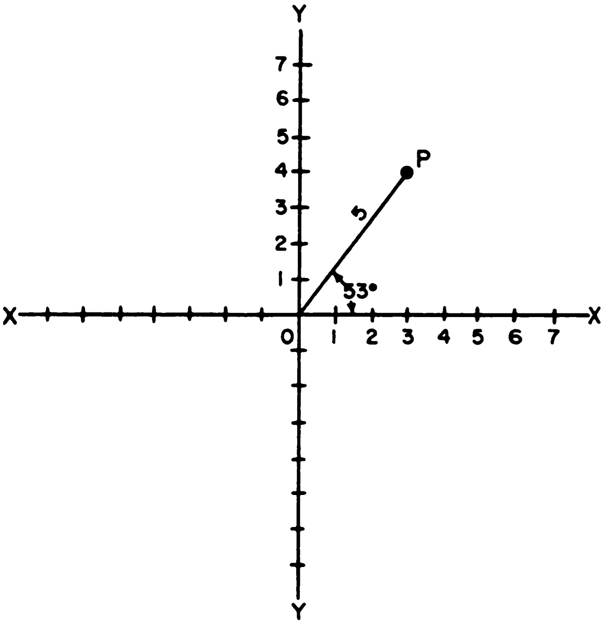

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Figure 3-10.—Polar coordinate system.

In describing the location of a point, the coordinates are placed within parentheses. The linear value is always written first. The coordinates of point P (fig. 3-10) are written: P(5, 53°). Thus, point P is five units from the origin along a line that forms an angle of 53° with the X axis.

Three-Dimensional Coordinate System

Until now we have assumed the target would be in the same plane as own ship. If a target is not on the surface of the earth, three dimensions are required to describe its position.

To locate a point not in the reference plane, the point's deviation from the reference plane must be described. The deviation is its height measured from the reference plane. The deviation can be described by either an angular (elevation) or linear (altitude) value.

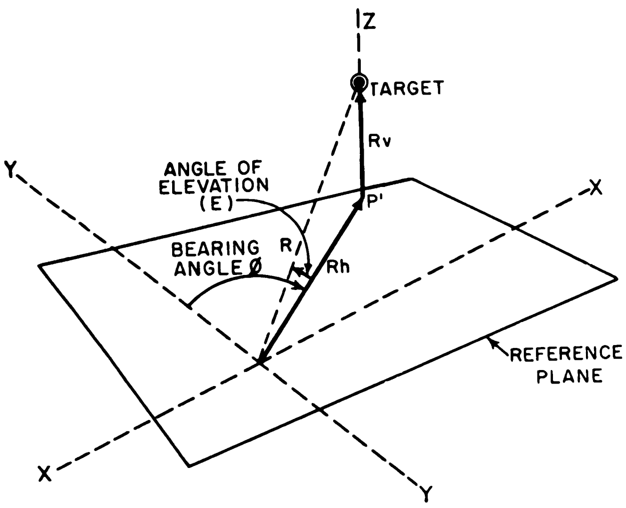

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Figure 3-11.—Three-dimensional polar coordinate system.

When the angle of elevation is used (fig. 3-11), the angle is measured at the origin. One side of the elevation angle is in the reference plane. The other side, the line R, connecting the origin with the target, is in a slant plane.

The line, Rv, establishes point P in the reference plane. Rv is constructed perpendicular to the reference plane; thus point P is directly beneath the target. The polar coordinate, Rh, and the bearing angle, Ø, describe the position of point P in the reference plane. The third coordinate, describing target's position with respect to the reference plane, is the measured angle of target's elevation (E).

The linear value of target's altitude, Rv, can be computed from the right triangle (R, Rh, Rv) in figure 3-11. The distance (R) of the target from the origin and the angle of elevation are measured. The linear value of Rv can be found by the formula

$$Rv = \sin E \times R$$

The distance from the origin to point P in the reference plane can be found by the formula

$$Rh = \cos E \times R$$

The position of the target in figure 3-12 can be described by three coordinates. We first establish point P in the reference plane, directly beneath the target. The position of point P can be described by the rectangular coordinate (Rhx, Rhy). The altitude, Rv, is the third coordinate used to describe target's position. The altitude is measured along an axis perpendicular to the reference plane. This axis is usually labeled with the letter Z, and called the Z axis.

TRANSMISSION OF COORDINATES

Normally targets are detected by the ship's search radar. Target's position information is then transmitted to the fire control system by a coordinate system. Frequently the coordinate system used by the search radar must be converted to the one used by the fire control system. Sometimes the coordinates must be modified to compensate for the distance between stations aboard ship.

Coordinate Conversion

The coordinate system serves merely as a convenient device to describe the location of a target. The location of a target does not change when we employ a different coordinate system to describe it. In figure 3-13 we have located a point in each quadrant. Both rectangular and polar coordinate are given for each point's location. This is possible since both systems have the same frame of reference. When a point is plotted by one coordinate system, the other coordinate system's coordinates may be measured. This is a

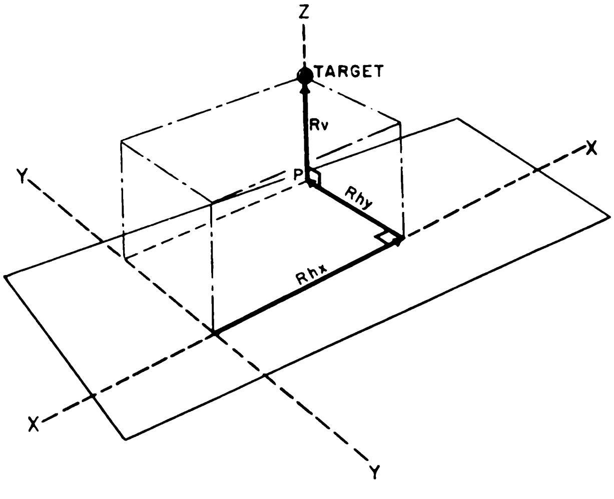

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Figure 3-12.—Three-dimensional rectangular coordinate system.

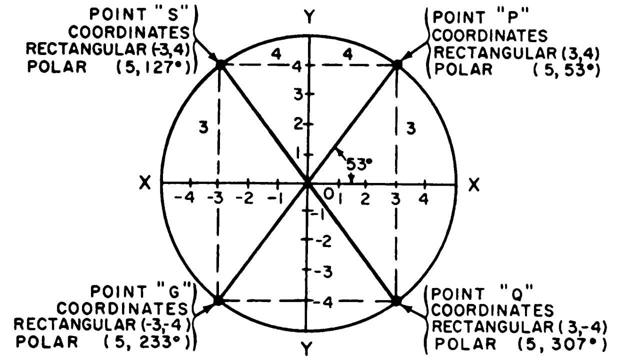

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Figure 3-13.—Location of points by rectangular and polar coordinate system.

graphic method of conversion. There are formulas that will convert coordinates, but we will not go into them here.

Translation of Axes

A coordinate system provides the information describing target's position in a form that can easily be transmitted. As you know, the coordinates are measured with respect to a reference point. When the station receiving the target's position information has its own reference point, the relationship between the two reference points must be established. If the distance between the reference points is measured by linear values, it is called translation of axes. Translation of axes is shown in figure 3-14.

In the example shown, the origin, O, is 3 units to the right along the X' axis and 4 units along the Y' axis above the origin O'. Therefore, the coordinates of O with respect to the origin O', are (3,4). The location of the target, with respect to the O origin, is established by the coordinates (4,5). The location of the target, with respect to the O' origin, is the summation of the coordinates between the origins and the target's coordinates with respect to O origin. In this example, the target's coordinates, with respect to origin O', are (7,9).

Rotation of Axes

When the frame of reference is transformed angularly, as shown in figure 3-15, it is called rotation of axes. The axes rotate about the origin. Therefore the range to the target (r) remains constant. The target's angular coordinate from th rotated axes (X', Y') is the summation of th angular coordinate from the X and Y axes an the amount of rotation of the axes. When bot translation and rotation are performed, a combination of both procedures is necessary.

FIRE CONTROL COORDINATE SYSTEMS

There are many variations of the polar an rectangular coordinate systems. The type o coordinate system used depends on the information available and the ease of mechanizing tha information. In fire control, two types of pola and one type of rectangular coordinate system are employed.

The SPHERICAL coordinate system (fig. 3-16) is a polar coordinate system. The ship is in the center of an imaginary sphere, whose radius is equal to range. The coordinates used to express target's position are:

1. Bearing angle (B) measured from own ship's centerline.
2. Elevation angle (E) measured from the reference plane.
3. Range (R) measured along the line of sight.

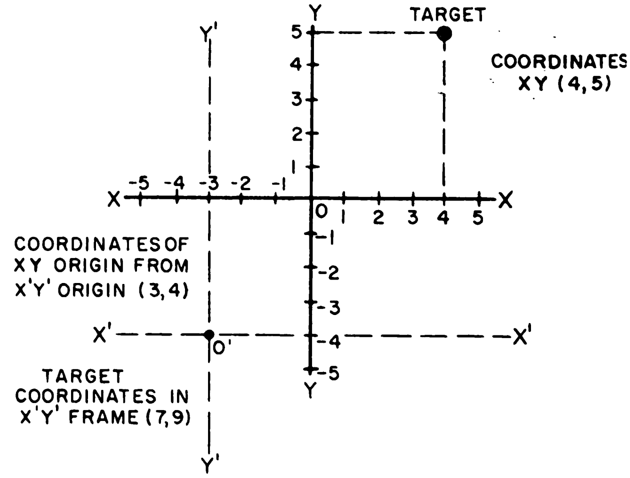

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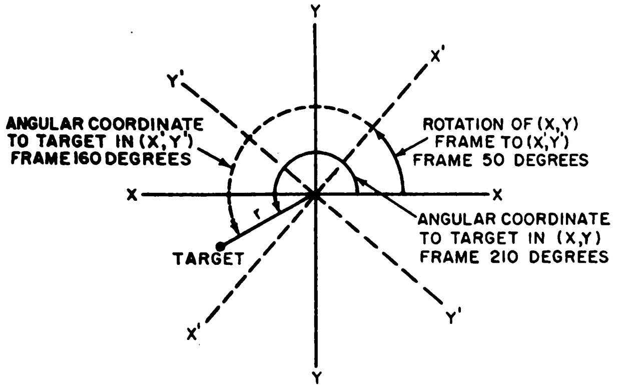
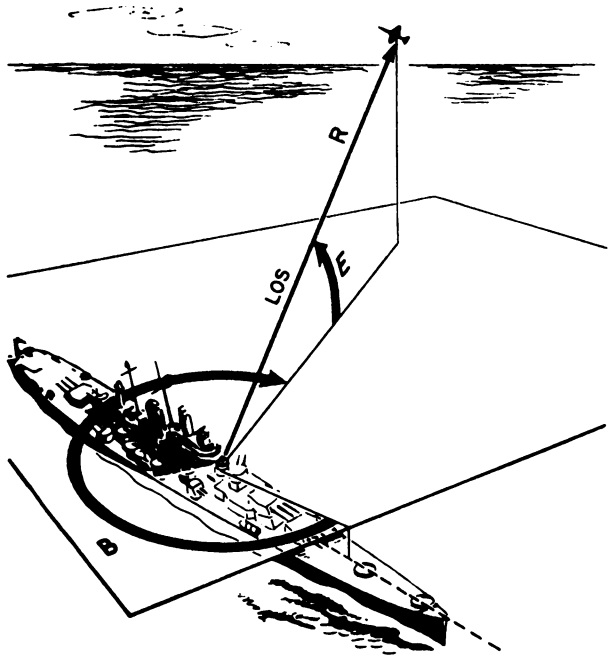
Figure 3-14.—Translation of reference frame.


Y
X'
Y'
ANGULAR COORDINATE TO TARGET IN (X',Y') FRAME 160 DEGREES
ROTATION OF (X,Y) FRAME TO (X',Y') FRAME 50 DEGREES
X
X
r
ANGULAR COORDINATE TO TARGET IN (X,Y) FRAME 210 DEGREES
TARGET
X'
Y'
Y

55.135
Figure 3-15.—Rotation of reference frame.



55.136
Figure 3-16.—Target position in spherical coordinates.

The CYLINDRICAL coordinate system (fig. 3-17) is also a polar coordinate system. The ship is in the center of an imaginary cylinder whose radius is equal to horizontal range. The height of the cylinder is equal to vertical range. The coordinates used to express target's position are:

1. Bearing angle (B) measured from own ship's centerline.

2. Horizontal (or deck) range component (Rh) measured in reference plane.

3. Vertical (or normal) range component (Rv) measured perpendicular to the reference plane.

The CARTESIAN coordinate system (fig. 3-18) is a rectangular coordinate system. The quantities used to express target's position are:

1. Horizontal range component in the east/west axis (Rhx).

2. Horizontal range component in the north/south axis (Rhy).

3. Vertical range component (Rv) measured perpendicular to the reference plane.

In each coordinate system the geometrical quantities of range, bearing, and elevation describe target's position. Any one of the three

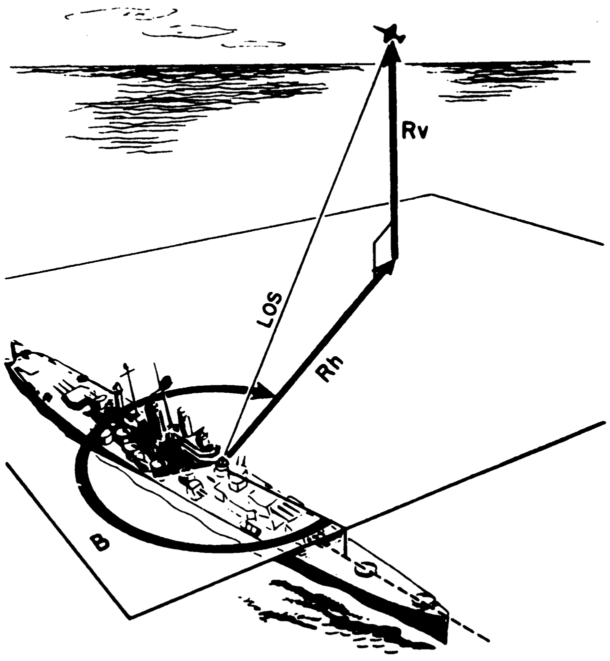


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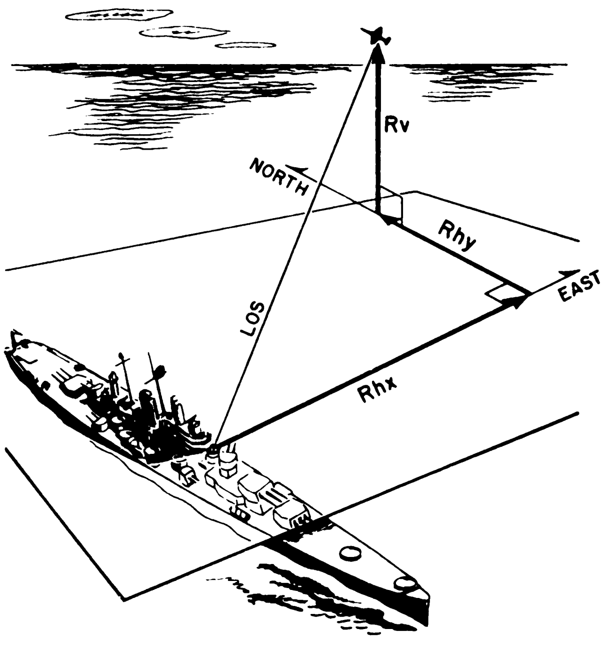
Figure 3-17.—Target position in cylindrical coordinates.



55.138

Figure 3-18.—Target position in cartesian coordinates.

coordinate systems can be used with any one of the four frames of reference. In all cases the reference point is contained within own ship or the guided missile.

DETECTION

TRUE BEARING AND SLANT RANGE

In our representative weapon system, you found that the principal indicator for representing the target's position is a PPI from which you can determine true bearing, By, and slant range, R.

Figure 3-19 shows how true bearing and slant range can be determined on a PPI. True bearing is determined by marking target position relative to the bearing marks around the indicator (scope) face. Slant range is arrived at by measuring the distance the target is from the point of origin (the point where the north/south axis and the east/west axis intersect). These determinations can be made by visual or electronic means.

As you can see from an examination of figure 3-19, target's rectangular coordinates can also be determined. The north/south and east/west axes correspond, respectively, to the Y and X axes of the previously presented example. Quantities measured in or to the north/south axis will be indicated as such by the modifier, y. Quantities measured in or to the east/west axis will be indicated as such by the modifier, x. Target rectangular coordinates, also can be determined visually or electronically.

The indicator just discussed may appear to be a graphical representation of the earth's surface. We, however, are aware of the fact that elevated targets can be detected and displayed on a PPI. This means that we have to determine the target's height or elevation to establish the position of an air target.

ELEVATION

The remaining dimension necessary to locate completely an object in space can be expressed either as an angle of elevation or an altitude. If one is known, the other can be calculated. A method of determining the angle of elevation or the altitude is shown in figure 3-20. The slant range (fig. 3-20,A) is obtained from the radar scope indication as the range to the target. The angle of elevation is that of the radar antenna (fig. 3-20,B). The altitude is equal to the slant

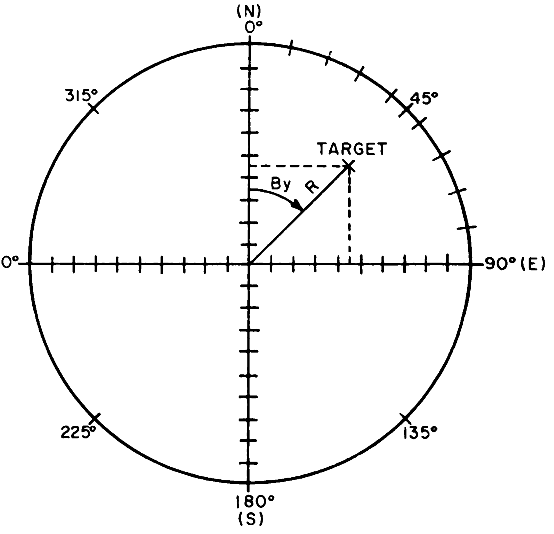


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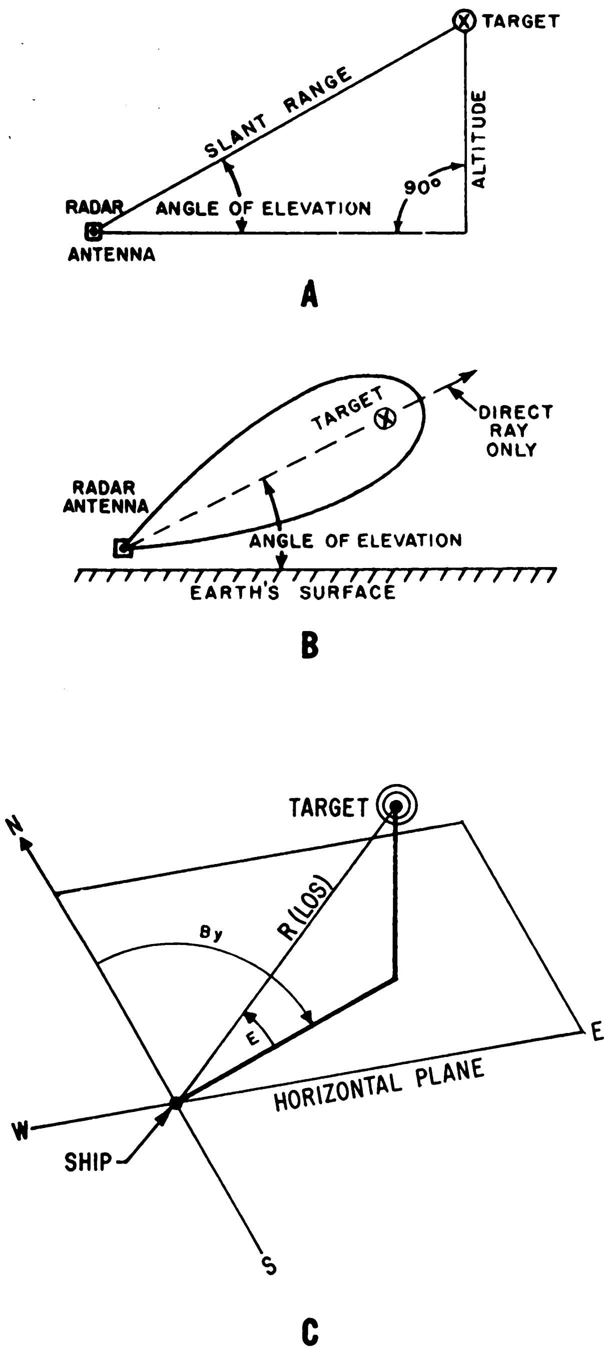
Figure 3-19.—PPI representation of By and R.



20.285
167.9

Figure 3-20.—A. Slant range; B. Angle of elevation; C. Targets present position.

range multiplied by the sine of the angle of elevation.

In radar equipments with antennas that may be elevated, altitude determination by slant range is automatically computed electronically.

Modern height-finding radars (3 dimensional radars providing range, bearing, and elevation data) utilize this principle to provide WDE with an electrical signal which is proportional to either target elevation (E) or target height (Rv). As stated in Basic Electronics, if either quantity is known along with slant range, the other can be determined. We'll use target elevation (E) for our problem.

Prior to designation of the elevation data, a determination is made as to whether the elevation data is reliable or not. This would depend upon the source of the elevation data and operating conditions. For our purposes, we'll assume that elevation data is reliable.

We now have true bearing, By, elevation, E, and range, R (fig. 3-20C). These earth oriented coordinates define target's present position. (Refer to OP 1700, Volumes 1 and 3 for exact definitions of the quantities and how they are measured.)

INFORMATION GATHERING

In fire control problems, we are required to find out first that a target does exist. Information is needed on the target, its characteristics, and the threat it poses so that a decision can be made as to which weapon system should be used to destroy the target. When a weapon system begins its task, it requires the location of the present line of sight. It must be supplied also with sufficient information on the target and own ship to determine the launcher positioning angle, missile-guidance beam capture point, and missile flight path (trajectory) information. Information gathering procedures are subdivided into target detection, target tracking, and methods of collecting ancillary data, figure 3-21.

DETECTION

The operation of the detection system initially becomes the target position, which is governed by the individual capabilities of the search radars.

An associated subsystem, the search radars, while not an actual part of the missile system, is essential to both Naval Tactical Data System (NTDS) and missile system operation (figure 3-22).

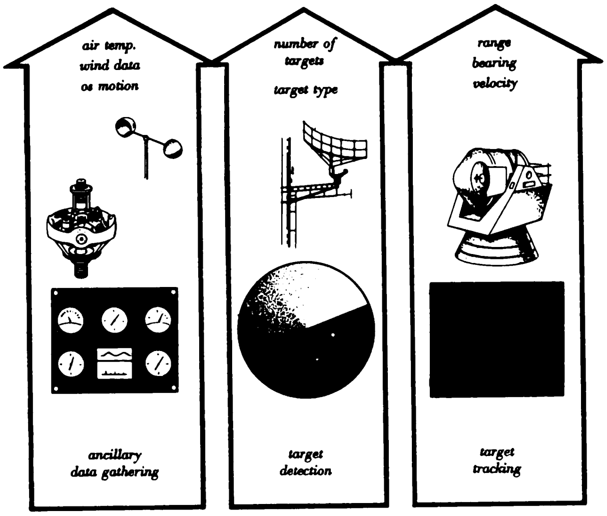


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Figure 3-21.—Information gathering.

A description of the Naval Tactical Data System is also presented. Assistance in accomplishing effective weapons control on SMS ships is provided by NTDS, which relies heavily on the various ship sensors and search radars, when performing this function.

Three-Coordinate Radars

Three-coordinate radars (AN/SPS-39, AN/SPS-48, and AN/SPS-52) are the primary source of air target information for the weapon system. These radars provide air search data consisting of range, bearing, and elevation angle to the weapon direction system. The air search data and synchronized Identification-Friend-or-Foe (IFF) interrogation information are displayed on operator consoles in the Weapon Direction System and Combat Information Center (WDS/CIC) area for target engagement evaluation. Electronic Counter-Countermeasures (ECCM) features, controlled at the radar, improve the display when jamming environments are encountered.

Two-Coordinate Radars

An alternate source of air target information for the weapon system, two-coordinate radars are the primary means for the detection of long range air targets. These radars (AN/SPS-29, AN/SPS-37, AN/SPS-40, and AN/SPS-43) provide range and bearing coverage and IFF capabilities similar to those of the three-coordinate radars, but do not furnish elevation information.

Navigation Radar

Radar Set AN/SPS-10 is a short-range, two-coordinate, unstabilized fan-beam radar capable of good discrimination in range and bearing for surface search surveillance and low flying aircraft.

Naval Tactical Data System/ Weapon Direction System

NTDS is a high-speed, digital-data processing, display, communication, and data conversion system that provides tactical data used for effective fleetwide defense against all types of enemy targets. The NTDS coordinates collection of tactical data from sources both internal and external to own ship. Own-ship data inputs to NTDS are received primarily from search radars, IFF equipment, electronic warfare (EW) equipment, sonar, and navigation and communications equipment. These data inputs are supported by inputs received from other ships, aircraft, and shore stations via data links. The NTDS correlates this data for a clear representation of the tactical situation, processes the data as required to aid in the decision-making process, and communicates all action decisions to WDS.

The WDS enables centralized control and monitoring of target engagements assigned to the missile fire control system. The WDS is used to initially evaluate targets, assign the targets to the missile fire control system, select the missile type and number to engage the targets, and evaluate the engagement results. Some weapon direction systems also have the alternate capability of entering and tracking targets. WDS

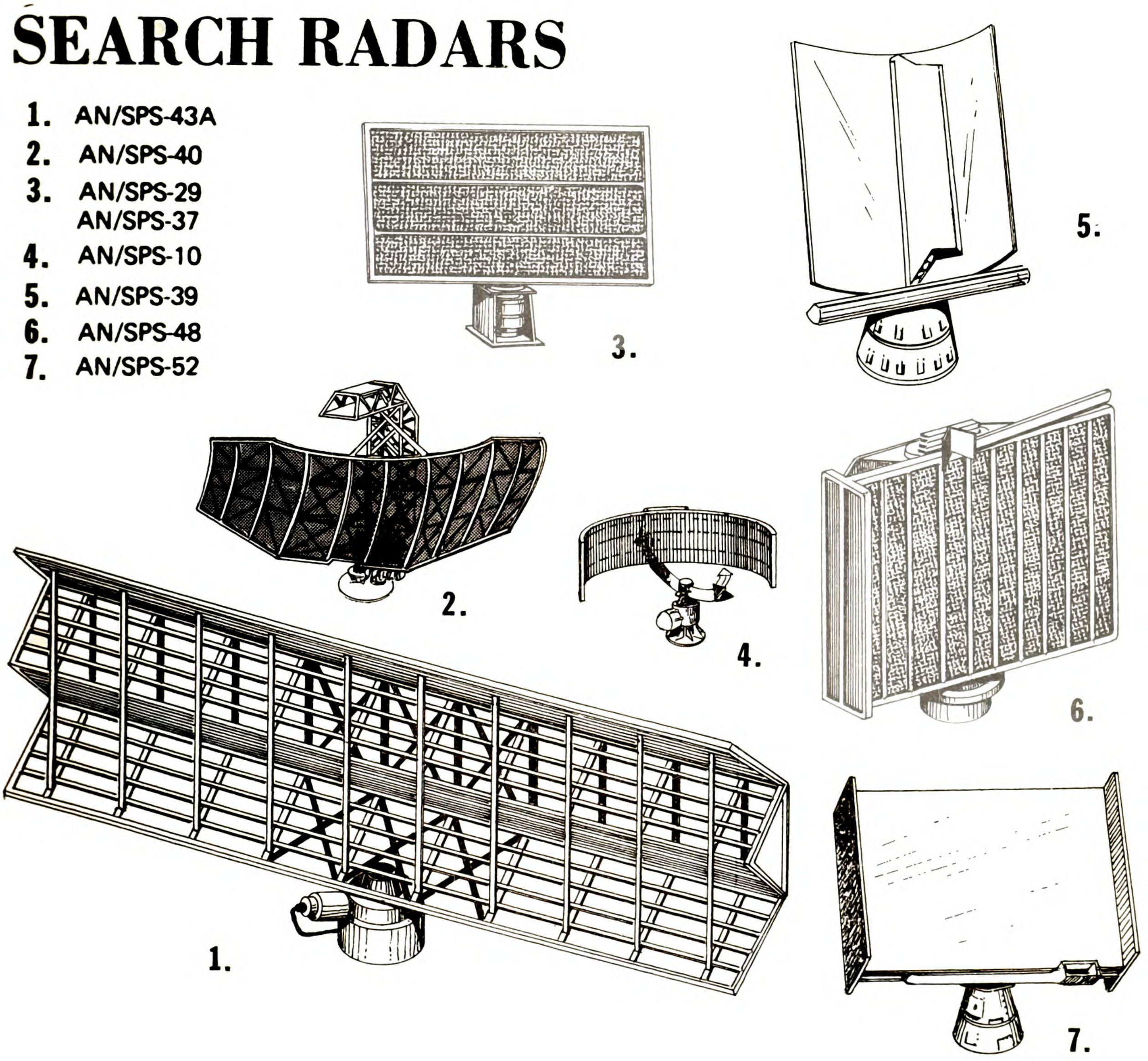

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Figure 3-22.—Search radars.

ancillary equipment provides control of the missile fire control systems, designation of optically tracked targets, and firing of missiles. In addition, the WDS ancillary equipment also provides indications of missile fire control system radar director train angles, missile fire control system tracking status, occurrence of missile flight, control of missile warmup, and a means of recommending changes to the ship's course to provide an unobstructed firing zone.

DATA PROCESSING GROUP.—The data processing group includes the computers and associated equipment necessary to receive, evaluate, and transmit tactical data. Information from the data processing equipment is routed to the data display equipment and designated to the missile fire control system. Tactical data are also distributed to the digital data radio links.

A general-purpose digital-computer Format Control Unit (FCU), sometimes called the Control Format Unit (CFU), provides digital processing techniques. This unit assumes the burden of routing the processing of ship motion data and weapons control data, thereby freeing storage space in the NTDS unit computers. A weapon control panel group provides indicators for monitoring data flow between the NTDS computer and fire control and launching systems. The weapon control panel also provides switches for operating personnel to use to control the fire control and launching systems and to fire missiles in accordance with tactical requirements and computer recommendations.

DATA DISPLAY GROUP.—The data display group is the primary means for displaying targets and communicating tactical data to the NTDS computer.

The Plan Position Indicator (PPI) display consoles accept, process, and display radar data from a shipboard or Airborne Early Warning (AEW) radar, sonar data from own-ship sonar, and computer track data from the unit computer. The PPI display consoles utilize input data that presents to the operator a continuous display of the tactical situation. Controls on the PPI display consoles permit the operator to enter tactical data and decisions into the unit computer, thus making the information available to other display consoles in the data display group. In addition, ECM and ECCM operations are monitored and coordinated to minimize the effects of jamming and other forms of interference.

Height/size video display consoles are used to measure target height and to analyze raid size.

DATA TRANSMISSION EQUIPMENT.—Radio transmission equipment provides an automatic, high-speed computer-to-computer digital communications link (Link 11) between NTDS ships, and between NTDS ships and Airborne Tactical Data System (ATDS) stations or Marine Tactical Data System (MTDS) stations.

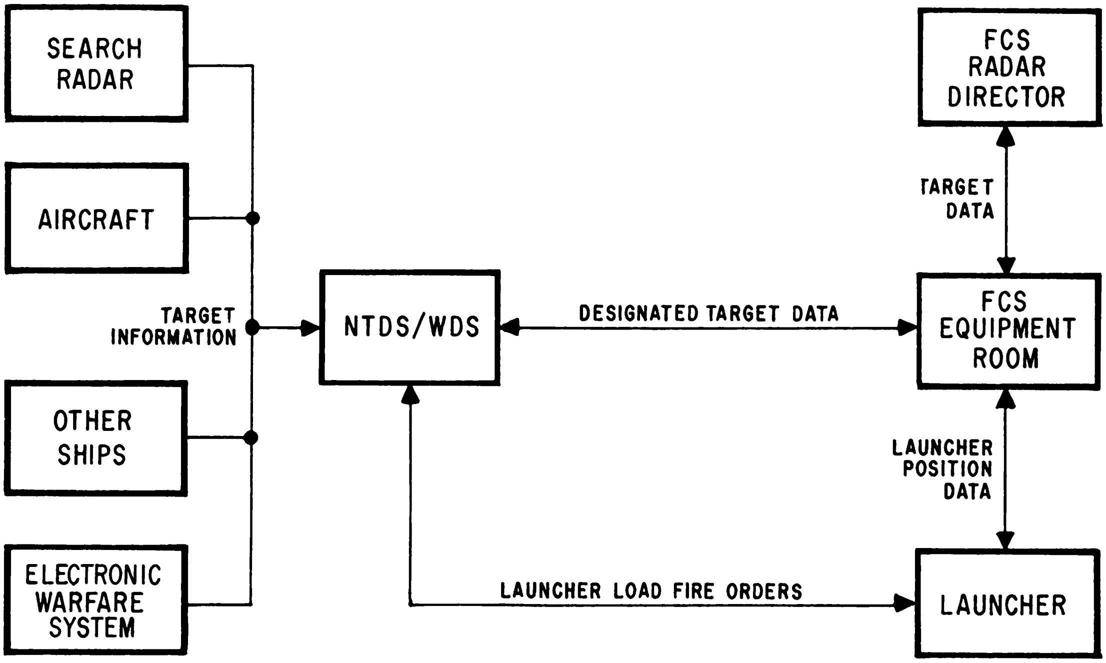

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Figure 3-23.—Typical TARTAR weapon system block diagram.

The Link 4A Digital Data Communications Control System is a fully automatic, high-speed data transmission system used in aircraft control. This system is used for (1) transmitting interceptor vectoring data, commands, and data pertaining to the aircraft target or designation; and (2) receiving messages concerning the aircraft heading, altitude, air speed, and tactical readiness.

Link 14 transmits, semiautomatically, computer-controlled target data from NTDS ships to non-NTDS ships via conventional radio-teletype equipment.

For a basic block diagram of a typical TARTAR and TALOS weapon system see figures 3-23 and 3-24 respectively. The TERRIER weapon system is fundamentally similar to the TARTAR block diagram.

TRACKING

The process of maintaining a line from the fire control angular tracking radar set in coincidence with the RF reflected energy from the target is called tracking, an example of which is shown in figure 3-25.

For a fire control system to implement the solution to the fire control problem, it must receive information on target position (range, bearing, and elevation), and target motion. This information is the principal input to any guided missile fire control system.

The Director or Radar Set

The director or radar set can search for, detect, acquire, and track a target; and it can in one radar control system, "capture" and guide a missile. Let's stop and consider the

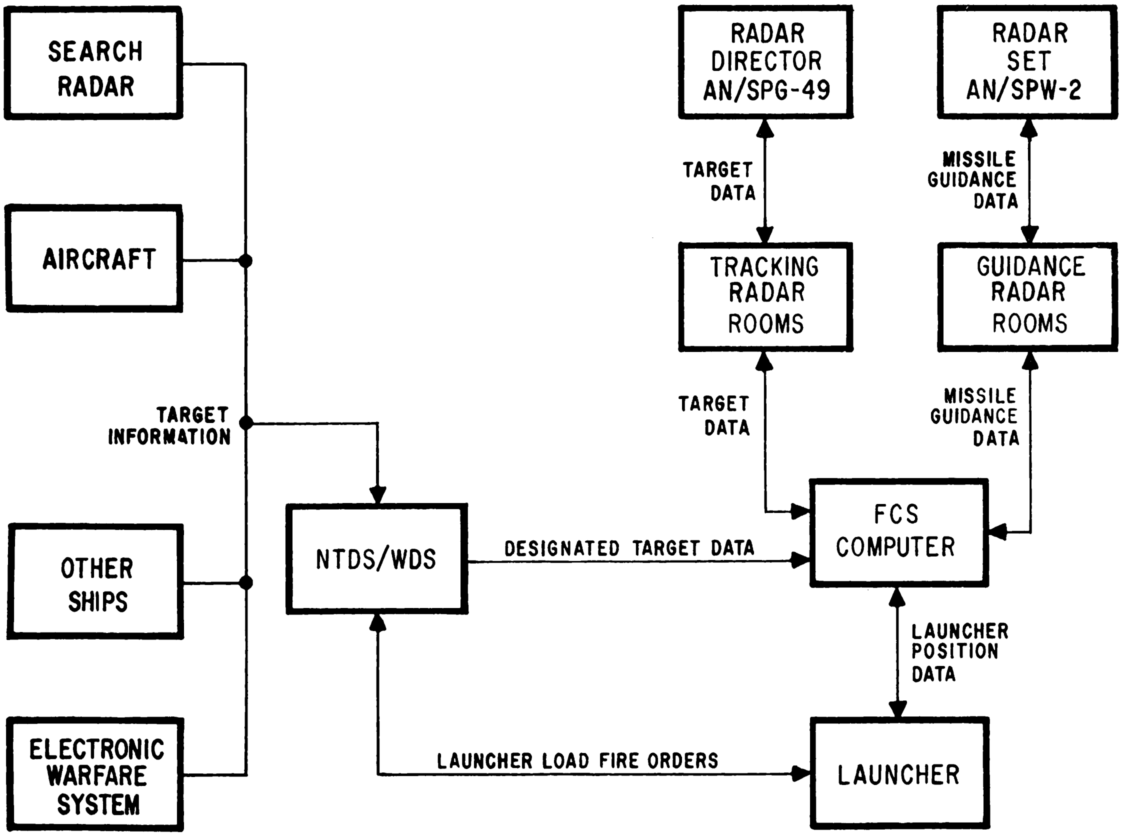

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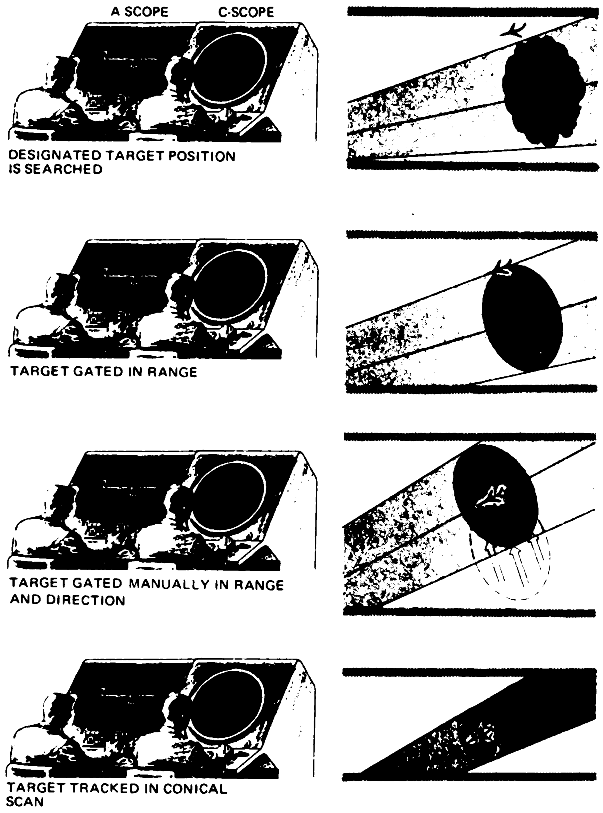
Figure 3-24.—Typical TALOS weapon system block diagram.


A SCOPE
C-SCOPE
DESIGNATED TARGET POSITION IS SEARCHED
TARGET GATED IN RANGE
TARGET GATED MANUALLY IN RANGE AND DIRECTION
TARGET TRACKED IN CONICAL SCAN

167.717
Figure 3-25.—Radar tracking.

terms "director" and "radar set." A director may contain a radar and/or optics for tracking and ranging, and it is usually manned. A missile director has no optical tracking device or rangefinder but relies on its radar set for tracking. It is not manned in the sense that a man is located inside the antenna supporting structure. True, there is an operator in the radar control room; but his primary function is to monitor the equipment. In the rest of this discussion we will use the term "radar set," rather than director, because that name is more descriptive of the function of a missile director.

The radar set described here is an automatic target tracking and missile guidance radar. It normally receives target designation signals from the weapon direction equipment, via the fire control computer. The designation signals position the radar set at the designated range, bearing, and elevation. If the radar set does not acquire the target immediately the fire control computer originates a search program for the radar set to seek out the target. If the ship has more than one fire control system, designation between systems is possible. Designation from another fire control system, called "Inter-Director Designation" or "IDD", is accurate and a search program is not needed.

When the radar set acquires the target in range, bearing, and elevation the radar set locks on the target and starts to track it. Tracking circuits within the radar set automatically keep its tracking beam on the target. Target position is continuously transmitted to the computer. The computer and the radar set working together solve for the target's rate of movement about the ship by calculations based on the line of sight movements.

The radar not only tracks the target, but also transmits radar beams to control the missile and guide it to the target. In the case of the one radar beam-rider missile the radar set will transmit simultaneously, on a common nutation axis, three distinct beams—the tracking, capture, and guidance beams. A narrow tracking beam first acquires and tracks the target. The wideangle beam captures the missile after launch, and holds it until it enters the narrow guidance beam that guides it to the target.

Where a semiactive homing missile is used, the radar set will transmit simultaneously, on a common nutation axis, a tracking beam, and an illuminating beam. After the missile is launched it will lock on to the illuminating radar's energy reflected from the target, and home on it. If a missile whose guidance is a combination of beam-rider and semiactive homing is launched, the radar set will transmit a tracking beam and a beam-riding guidance beam, and later switch on an illumination beam.

The radar set consists of two major groups of equipment: an antenna group, and a control and power group. The antenna group, which is located above deck, consists of a pedestal (barbette) upon which is mounted the antenna and the necessary electrical and mechanical components required to stabilize and position the antenna. Housed inside the mechanical structure of the antenna group are the transmitting, receiving, and associated microwave circuits. Here, too, are located the gyroscopes that space-stabilize the antenna, and thus the radar beams, to compensate for the roll and pitch of the ship. You will study these gyroscopes in chapter 10.

The control and power equipment group is located below decks in a compartment usually called the radar room. This room contains the radar consoles used to operate, monitor, and control the radar set. Also located in the radar room are the cabinets containing the power supplies that provide the operating voltages for the various units in the radar set.

Tracking From a Moving Ship

Movements and rotations of the launching ship are a basic source of tracking interference. These motions, such as pitch, roll, and yaw (fig. 3-26), are not part of the actual fire control problem; nonetheless, they almost always occur in a fire control situation. Since these motions do occur but are not a part of the fire control problem, it is necessary to compensate for them in some way other than as part of the computation. This compensation is usually provided by stable elements, such as the gyroscope, so that the motion interferences are removed from the input data to the fire control computer.

The gyroscope maintains a direction that remains fixed in space in the presence of motion, and yet can be changed in response to a command signal.

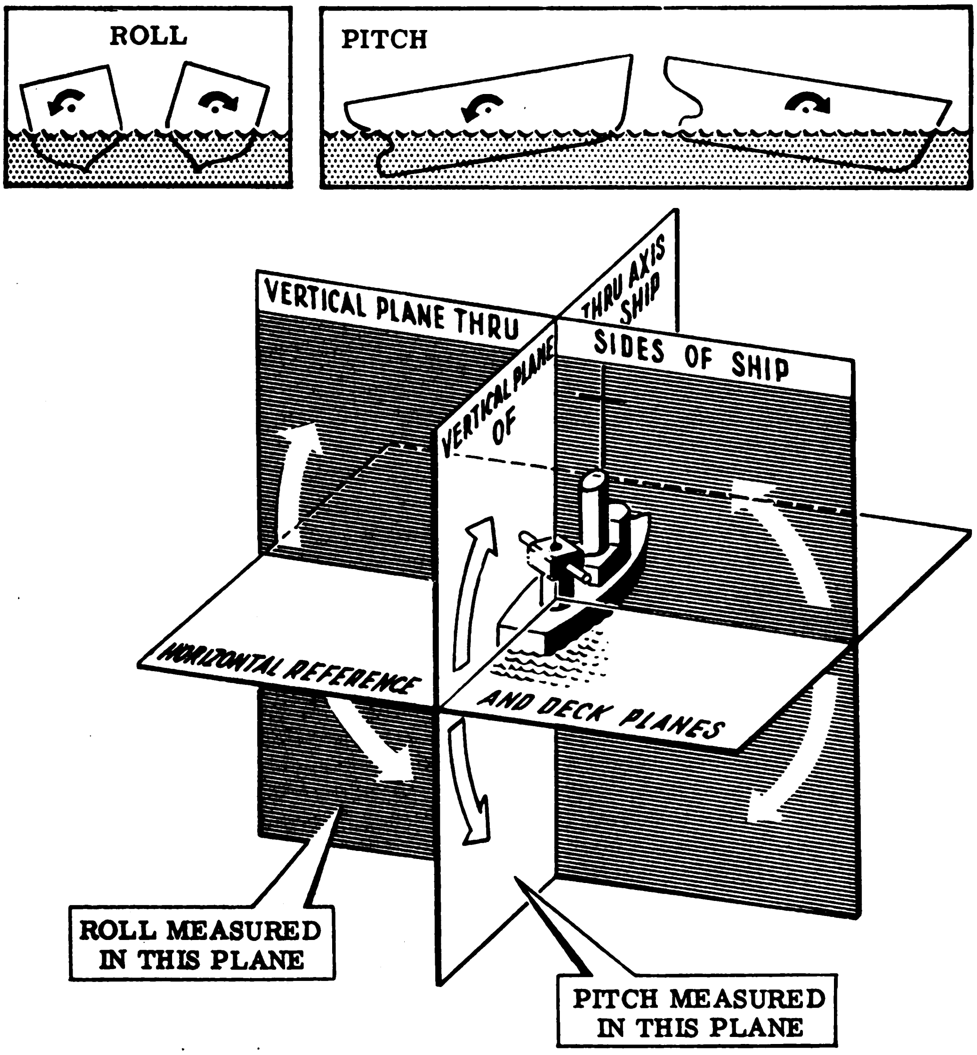


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Figure 3-26.—Roll and pitch.

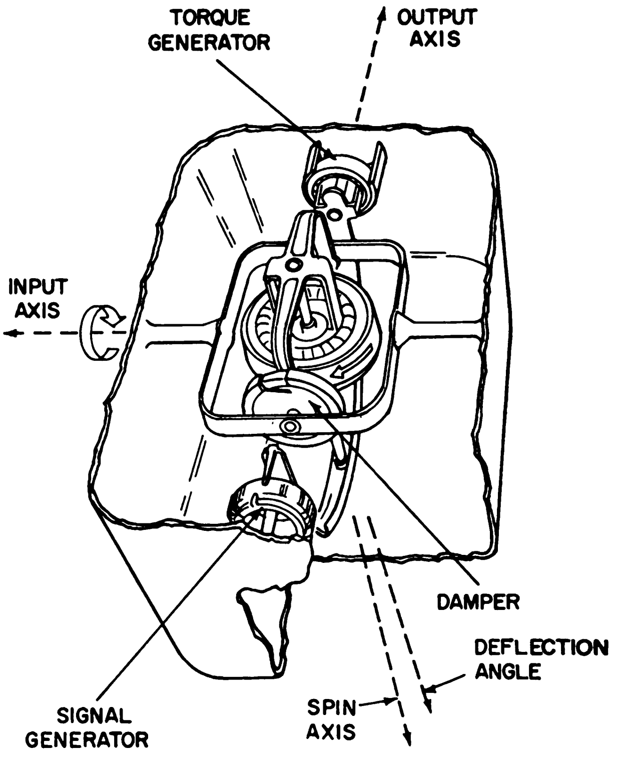
With all ships subject to motions of pitch, roll, and yaw, and tracking high speed targets, the apparent motion of the target would be quite high.

As an aid in understanding the operation of gyros in a tracking loop, a simple tracking loop which can track a target in a vertical plane will be analyzed. As mentioned before, the basic theory of operation of gyros will be described in chapter 10.

An illustrative single-degree-of-freedom gyro is shown in figure 3-27. When this gyro is used in a tracking loop, the configuration that results is similar to this figure.

The radar antenna is the device which receives the RF energy reflected from the target. When the target and ship are relatively (in terms of bearing and elevation) motionless, the system is at rest. The radar RF tracking axis will be nulled with the line of sight to the target, and therefore the antenna positioning signals from the tracking error circuits will be zero. The gyro will remain fixed with reference to space, and the signals to the antenna drive system will be zero. But, if the ship were to pitch downward, the antenna, being mounted on the ship, would tend to move downward also. This provides a rotational velocity of the gyro case which causes the gyro to precess at a rate proportional to the downward pitching motion. The precession is detected by a signal generator, the output of which activates the antenna drive system to move the antenna upward at the rate equal to the downward pitching motion. In this manner, the antenna is maintained stabilized with respect to space as represented by the position of the gyroscope.

When the target moves, the line of sight to the target will be displaced from the RF tracking axis as indicated by the antenna position. The tracking error detection circuits will produce correction signals to drive the torque motor. The action of the torque motor will have two effects. First, it will cause the signal generator to produce a signal causing the antenna to move to follow the target, and consequently, causing the RF tracking axis to follow the line of sight to the target. Second, it will cause the gyro to reposition itself with respect to space, that is, to reposition the RF tracking axis which is always driven to correspond with the gyro position in space.



167.718
Figure 3-27.—Single-degree-of-freedom gyro.

Special conditions which cause problems are the tracking of low angle targets in which reflections from the sea, as illustrated in figure 3-28, cause varying results. If a target is large, such as a surface ship, the tracking radar may not lock on to any one part of the target, but may receive strong signals alternately from the bow, the mast, or other area of the target. This causes the radar set to indicate a motion of the target where none exists.

DATA PROCESSING

The basic functions of the fire control computer are the computations of: lead angle and launcher orders, radar repeat back circuits, and in some cases, guidance transmitter positioning orders. In the beam rider missile system the computer must also "program", or continuously reposition, the guidance transmitter. This positions the guidance beam to an intercept point with the target, thereby causing the missile to collide with the target. The inputs to

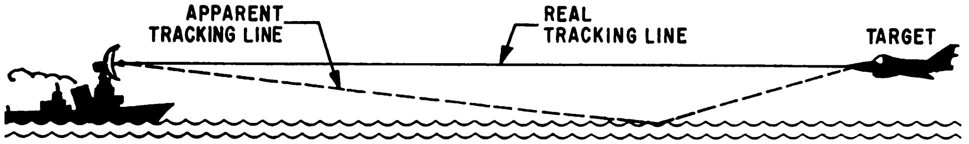


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Figure 3-28.—Tracking problem - low angle target.

the computer are comprised of the target positional data from the tracking radar, the required ballistic and environmental data, and positional data concerning the ship itself.

For simplification and accuracy of operation the computations must be performed in some reference frame which has been selected to permit a simplified solution to the fire control problem. Data received by the fire control computer is rarely measured in the reference frame and coordinate system which are used for computation. Because different frames and systems are used, the input data, particularly the tracking data, must be converted to the frame in which the data will be employed. When the prediction angle is determined, it must then be converted to the frame in which the missile launcher operates. One of the major functions of the computer, then, simply is to convert the data to useful forms.

COMPUTER SUBSYSTEM

As its input, the computer (fig. 3-29) receives the target position from the tracking radar and the necessary ancillary data. The position of the tracking radar is compared with and maintained coincident with the line of sight of the target (RF axis) by the tracking system. From the input data, the computer generates the intercept point and the computed position of the launcher. The launcher drive system then drives in response to the signal, until the launcher position and the computed launcher position are coincident.

TYPES OF COMPUTERS

A computer is a device or a machine in which physical operations perform mathematical computations to provide logical or numerical results. Computers are usually classified into two basic types—analog or digital. Analog computers essentially deal with a continuous measurement of a function, while digital computers deal with counting discrete values of a function. Basically, the analog computer measures and the digital computer counts.

Analog Computers

An analog computer is one in which numbers are represented by physical magnitudes, such as the angle of rotation of a shaft or the magnitude of an electrical voltage or current. The basis of analog computation is the establishment of an analog or scale factor between the data and the computing mechanisms in the computer. The limit of precision of an analog computer is determined by how precisely the scale is read, which is limited by how accurately gears are ground, resistors, inductors, and capacitors are manufactured. The continuous measurement of a variable in an analog computer makes it useful in fire control problems dealing with varying inputs as would be presented by an aircraft problem. On the other hand, because the computer operates on a continuous basis it cannot jump from one problem to another. Switching is possible, but it involves a loss of time thus slowing down the speed of a solution. Therefore, analog computers are usually used for solving only one problem at a time.

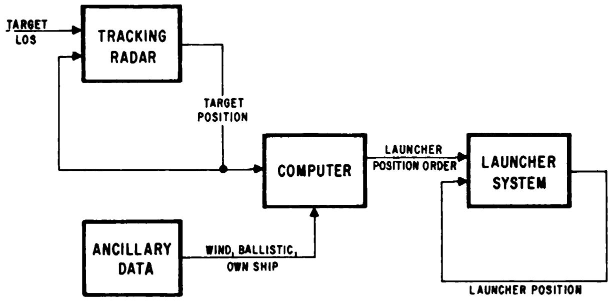

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Figure 3-29.—Computer subsystem.

Digital Computers

Electronic pulses are used to represent the digits of numbers on which arithmetic operations are performed. Digital computers possess the capability of a higher degree of accuracy than analog computers. The limitation of precision of a digital device depends only on the value of the least significant bit (LSB) of its registers.

A digital computer processes data consisting of defined numbers, the digits of which represent quantities undergoing computation. The computer sees these numbers as a group of discrete signals, each subgroup of discrete signals representing one of the digits of the entire number. Digital computers perform arithmetic operations by counting these discrete signals.

CALIBRATION

Calibration is the process by which computer circuits are adapted to meet specific fire control problems. In most cases, it would be impractical to create a computing device which could cope equally well with all possible situations. Hence, computers are calibrated so that they may successfully cope with the most likely situations. Basically, there are two types of calibration performed on a computer, static calibration and dynamic calibration. A few examples will serve to illustrate the use of static calibration.

Static Calibration

Assume that we are to fire a surface-to-air guided missile at a target and that we know, for this particular application, that the target will be either a very short range target or a very long range target. For the short range target, it is desirable to compute a prediction angle and solve the fire control problem as though the missile were not guided. However, for the very long range target, it is desirable to fire the missile at the same bearing as the tracking LOS and also at a fixed elevation angle to get the missile to optimum cruising altitude as quickly as possible. In other words, the prediction angle for the short range target is the normal prediction angle and varies with the situation; the prediction angle for the long range target is fixed regardless of the target position (aside from the fact that it is classified long range).

Since these are the only two situations which we expect to encounter, we may then calibrate our computer so that it automatically gives us the normal prediction angle for short range or the specific fixed prediction angle for long range.

In addition, we may further calibrate our computer by assuming that for short range targets the curvature resulting from gravity will have a nominal value and that the variation of this nominal value will be small enough to be neglected. This is especially true if it is determined that the missile may be guided easily to compensate for this variation without causing excessive acceleration of the missile. In this case, then, we may calibrate our computer for short range problems by adding a fixed curvature correction. This calibration practically eliminates the curvature correction computer, thereby greatly simplifying our machine. Of course, using all of these calibrations restricts us severely since we may now attack only very long range or short range targets.

Dynamic Calibration

Suppose, now, that we consider attacking targets at all ranges. We can determine a nominal desired value of prediction angle which varies as a function of range. In other words, for this guided missile system we would like to vary the angle between tracking LOS and launcher LOF so that we have a complete spectrum of prediction angles varying in a fixed manner from the long range solution, discussed previously, to the normal prediction angle used for our previous short range problem. We would instrument this program by calibrating our computer as a function of target range. Since this is a constantly varying factor, we call it a DYNAMIC calibration. In the same manner, we might calibrate curvature correction as a function of range, thereby simplifying our computer via a dynamic calibration.

Another kind of dynamic calibration is the use of sensitivity control. Suppose we are guiding a missile towards a maneuvering target. There are two prime considerations: one is that the missile follows the target sufficiently close so that it assures a hit. The second is that the missile is not required to perform accelerations large enough to cause it to fly out of its guidance beam if it is a beam rider, or so large that it cannot comply with the command.

It is not necessary for the missile to follow target maneuvers exactly while the range difference between target and missile is large. In this case it is desirable to smooth the missile's response to target motion. However, as the missile approaches the target, it becomes more and more necessary for the missile to follow target's maneuvers to avoid a miss. Hence, a program ay be implemented, via dynamic calibration, to ake the missile's sensitivity to target maneuers small at large missile-target range differnces, but increase according to a fixed program s the range difference decreases.

ATA CONVERSION

Data conversion is the process of transforming ector components from one coordinate system to nother by electrical and/or mechanical means.

In a stabilized fire control system, the amount f roll would be sensed by a gyro or stable lement and the deck elevation angle would be hanged to compensate for the roll. This is shown n figure 3-30.

If measured tracking data is acquired in an nstabilized frame, and the fire control computer perates in a stabilized frame, a transformation rom unstabilized coordinates must be made at he computer input. Similarly, if the launcher perates in an unstabilized frame, the reverse ransformation is required at the computer output.

In general, the computation of the fire control solution is accomplished in geometrically stabilized coordinates. Input data is usually stabilized at the tracking radar or in a data converter associated with the radar. If the computer operates in stable coordinates, its output is naturally in stable coordinates. However, the output may be used to drive a device whose base is not stabilized, such as the launcher. In this case, data conversion is required at the computer output to make the drive signals compatible with the base of the driven mechanism.

Data conversion is required because different reference frames use different measuring equipment which inherently make measurements with respect to their own reference system, as explained previously in this chapter.

MISSILE CONTROL

When the line of sight to the target has been established and the prediction angle (launch, capture, and intercept point) has been determined, the fire control problem has been solved. Next, the solution must be put into effect. The launcher positioning system must position the launcher properly as required to achieve capture of the missile within the guidance beam. The guided missile must receive orders to follow. The orders may be given prior to launch and during flight. Some guided missiles require continuous instructions from the fire control system aboard ship during missile flight.

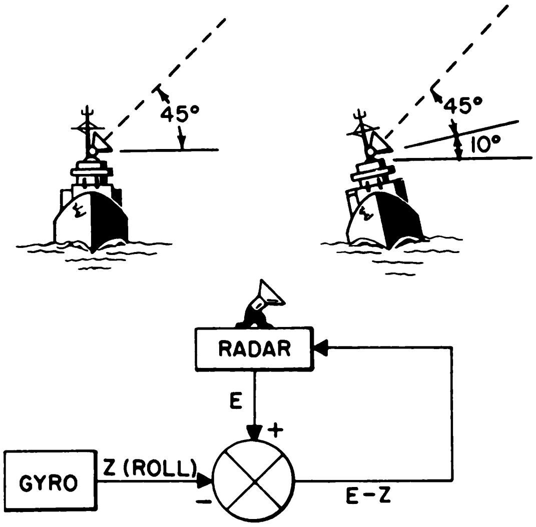

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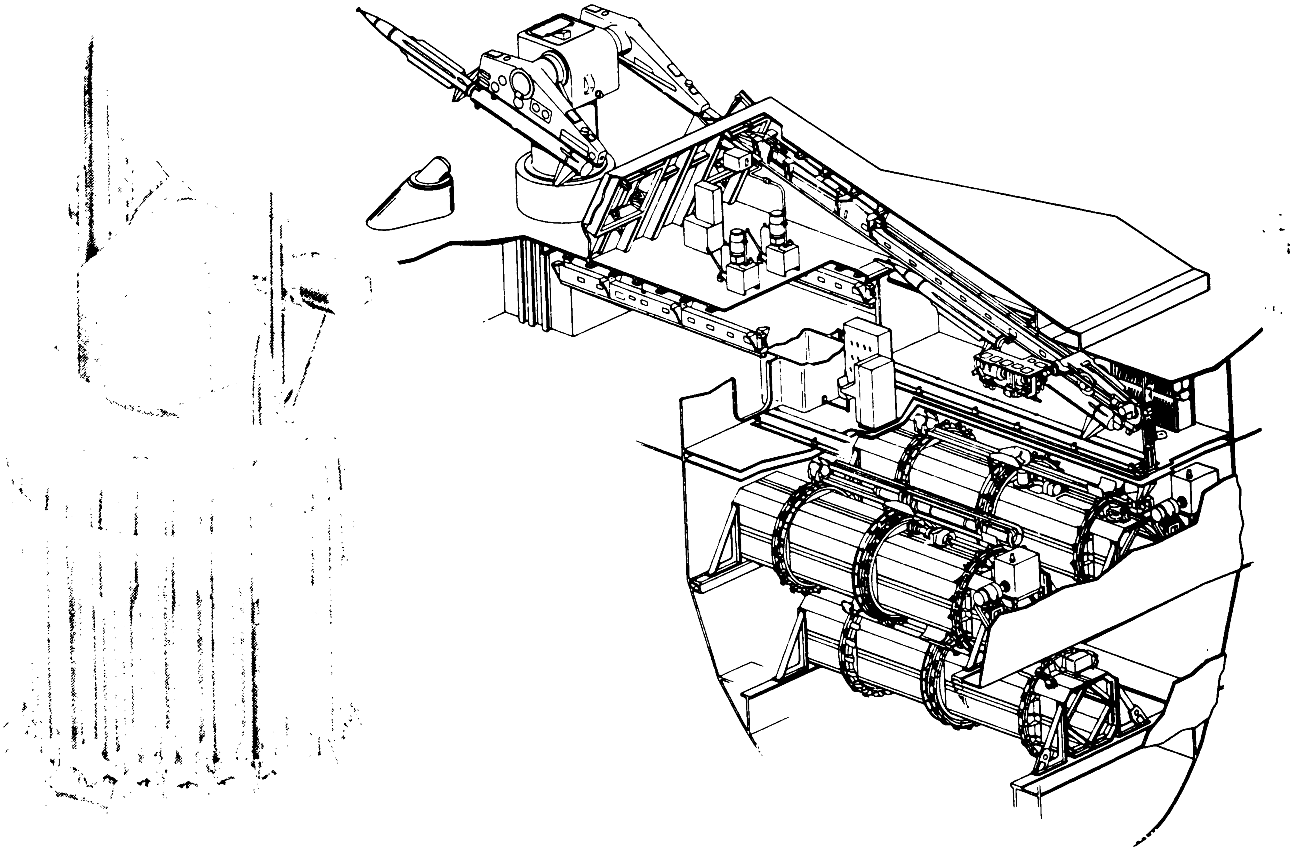
Figure 3-30.—Roll stabilization.

LAUNCHING

Some launching systems are so big and complex, that they are fixed and require that the launcher return to a predetermined angle of elevation for loading. The loading angle may be vertical, horizontal, or near the horizontal. This loading at a prescribed angle of elevation is usually coupled with loading at a preset position in train. The schematic of typical TERRIER installation as shown in figure 3-31 illustrates the necessity of the launcher returning to predetermined angles of train and elevation in order for the loading operation to be accomplished.

When missiles are small enough (usually those with integral propulsion systems) loading may be conducted for a continuously rotating launcher by making the line of missile transfer coincident with the train axis of the launcher, and thus independent of launcher train. In systems of this type, such as the TARTAR launcher shown in figure 3-31, missile transfer is completed when the missiles are deposited in the ready service ring. The next phase is to load them, by ramming, onto the launcher rail.

In general, the launching system must respond to certain types of orders, such as what to launch, where to launch, and when to launch. These orders are electrical signals normally



TARTAR launcher and storage facilities

typical TERRIER missile installation

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Figure 3-31.—Guided missile launching system.

sent from NTDS/WDS, and the fire control computer, to the launching system, via the fire control switchboard.

Selection of a Missile

A launching system will often have several types of missiles stored within its magazine, so it must receive orders regarding the type or types of missiles to be launched. In guided missile launching systems, both homing and beam-riding missiles may be available. The launching system must receive orders regarding which type of missile to launch. In addition to the type of missile, the launching system must know how many missiles to launch. For example, a guided missile launching system may fire one rail, or two rails at the same time, either once or continuously.

Flight Orientation

In order to launch a missile into a desired flight path, its initial flight orientation must be controlled by the launching system. Therefore, the fire control computer generates missile orientation orders to which the launching system must respond.

Guided missiles must be launched with minimum dispersion. For example, a beam-riding guided missile must be launched in such a direction that it intercepts a moving or stationary radar guidance beam. A homing missile must be launched so that it will be in a position to acquire and lock on to a target.

Basic Point Defense Launching System

The BPD launching system, figure 3-32, is a ready stowage area and a launching platform for eight guided missiles (AIM 7 series Sparrow III), and contains the necessary circuitry to drive the launcher in train and elevation and to relay signals from the fire control system to the missiles.

The launcher contains eight missile cells which have frangible fire-thru covers. Each cell has a guide rail that supports and guides the missile during launching. A missile-away switch initiates a step-over to the next cell in the firing sequence when the missile leaves the rail.

The Basic Point Defense System is covered in more detail in FTM 3&2 Supplement 2, NAV EDTRA 10209-S2.

GUIDANCE

Guided missiles have self-contained guidance or remote guidance which provides some degree of inflight control. The inflight control may exist only for a short period during flight, or throughout the entire flight. For guided missiles, it is not simply a problem of finding the direction to aim the missile (launcher positioning), but one of navigating the missile. There are missiles which combine the features of more than one type of guidance system, such as missiles which are remotely guided from the launching ship to the intercept area of the target and then guided to intercept themselves by their own homing devices.

Homing

As discussed in chapter 2, homing systems can be divided into three types, depending on the source of the energy detected by the tracking sensor within the missile.

a) active homing
b) semi-active homing
c) passive homing

ACTIVE HOMING.—In an active homing system, the transmitter of energy which illuminates the target and the receiver which receives the reflected energy from the target are both contained in the missile. A simple homing system consists of a transmitter and receiver of microwave energy for target detection and tracking of the target, a computer to calculate the required missile line of sight position to the target, and missile control equipment to direct the missile in response to the computer orders to intercept the target.

There are several advantages of a missile using active homing.

1) Once homing starts, the missile is completely independent of energy transmitted from an external source and of any external guidance information.
2) The fire control system of the launching ship may engage another target as soon as homing is initiated.
3) Long range target intercept is possible beyond the accurate fire control radar tracking range.
4) The launching ship has greater flexibility since it can maneuver, retire, etc., once homing is initiated.

SEMI-ACTIVE.—In a semi-active homing system, the transmitter of energy which illuminates the target is located outside the missile on the launching ship. The semi-active homing system operates in the same manner as the active homing system. Because the energy transmitter is no longer in the missile, but on the larger launching ship, the size and weight of the transmitter can be much greater, permitting the use of long-range, high power transmitters. Since the missile operates solely on energy which originates in the transmitter on the launching ship, the launching ship cannot break off the attack on the target once the missile is launched. Once a missile with active homing is launched, the launching ship is free to begin an attack on another target. With semi-active homing, however, the launching ship must continuously participate in the engagement until intercept occurs.

PASSIVE HOMING.—The third form of homing is passive homing which relies solely on energy emitted by the target. Because a passive homing system does not require an internal transmitter, it has the advantage of a relatively light weight missile as in a semi-active homing system, and missile independence of the launching ship as in an active homing system.

Missile Homing Control

Because the receiving, computing, and control equipment must be carried in a homing missile,

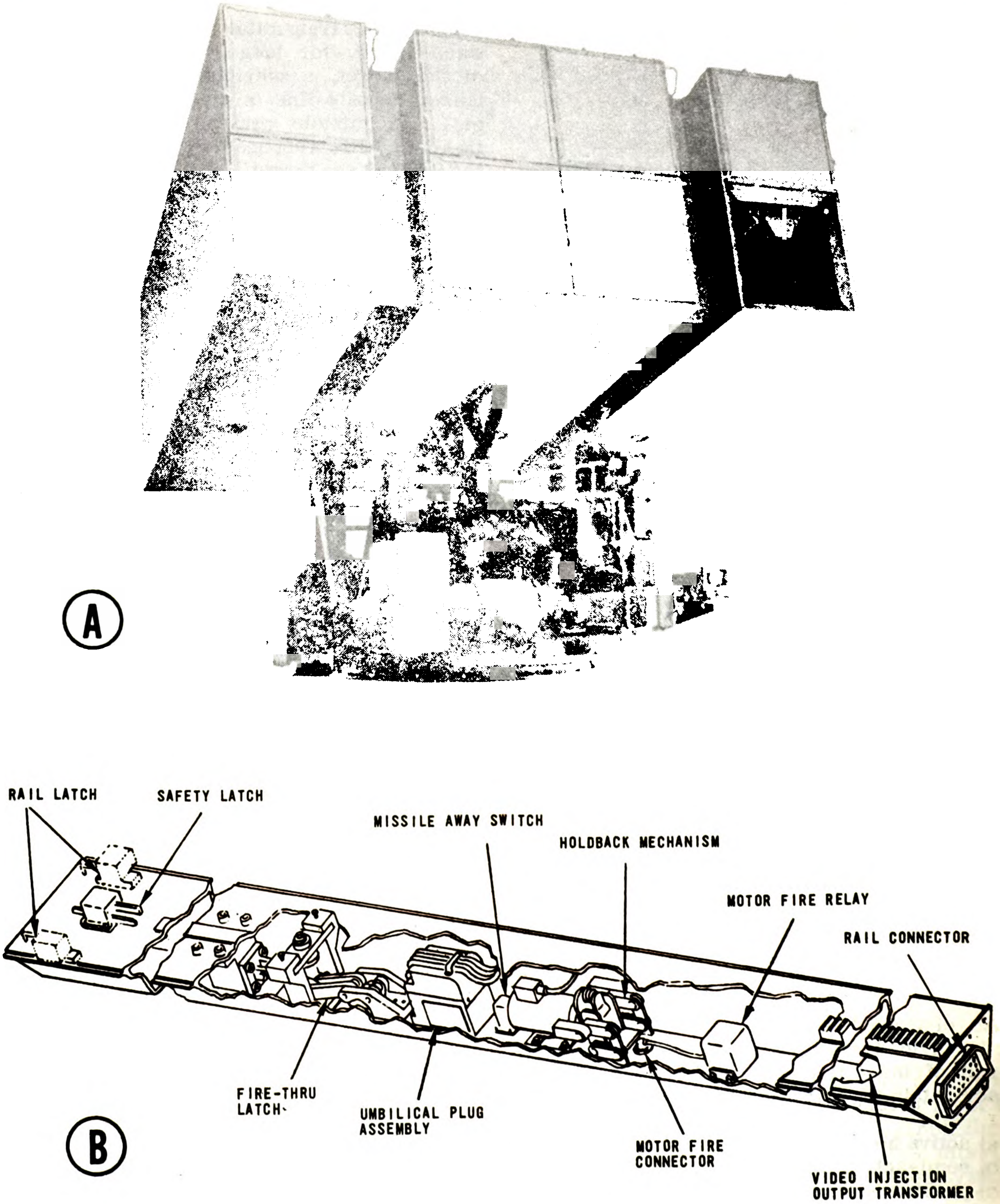

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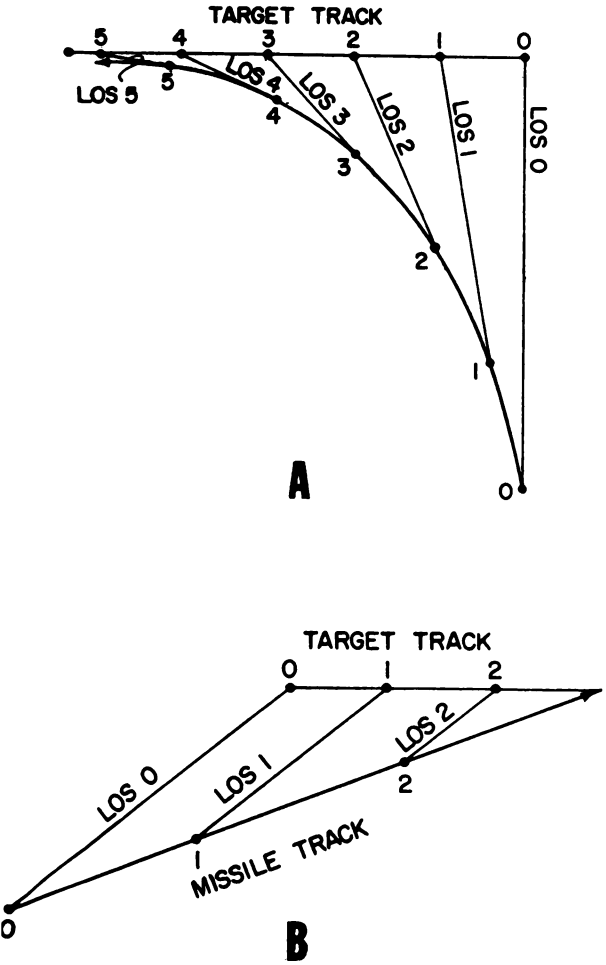
Figure 3-32.—BPD launching system: A. Launcher; B. Guide rail cutaway.



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igure 3-33.—A. Pursuit course; B. Constant bearing course.

he fire control problem should be solved as imply as possible. One of the oldest and simplest olutions is the pursuit course, illustrated in igure 3-33A, which is the path followed by a nissile which is always aimed directly at the arget.

The missile then flies its flight path coincident with the line of sight to the target. The eceiver can be a fixed detector whose tracking ine of sight is set in coincidence with the nissile axis, or flight path. Any deviation of he target line of sight from the tracking line of sight is the tracking correction signal. Because the pursuit path does not utilize any prediction angle, no computer is required and the tracking correction signal can be used as the missile control signal to reorient the missile flight path and tracking line.

Unfortunately, in a pure pursuit course the missile follows a curved path even when the target is following a linear course. A missile using a pursuit course must have very high maneuverability not only to follow this curved path, but also to correct launcher dispersion, gravity, forces causing flight path curvature, and any target maneuvers.

The requirements for missile maneuverability are greatly reduced if the missile flies a straight line path to intercept.

To fly such a collision path, it is necessary to maintain a constant line of sight. In order to comput the prediction angle, the receiver within the missile must determine not only target bearing and bearing rate but also target range and range rate. A computer is required in the missile to calculate missile flight path orders on the basis of data about the target. Once the missile flight path is directed properly, it is then necessary to maintain only the line of sight to the target stationary, and intercept must occur despite target evasive maneuvers. However, any instantaneous changes in the line of sight direction must be detected and corrected immediately. Because it is not physically possible to build a system which operates instantaneously, some more practical methods must be devised.

One such method is proportional navigation. In this system, as long as the line of sight does not rotate, the missile is maintained on its straight line path toward collision. If the line of sight begins to rotate because of target maneuver or any undesired motion of the missile, the missile flight path control equipment is ordered to turn the missile at a rate proportional to the rate of the line of sight rotation and in the proper direction to reduce the rotation of the line of sight to zero. When the rotation of the line of sight is reduced, to zero, the missile is held on its constant bearing path, figure 3-33B. A proportional navigation system requires data on target bearing and range and the rate of change of each to calculate the initial prediction angle. An additional requirement of this system is a second order control system which turns the missile at a rate proportional to the input signal.

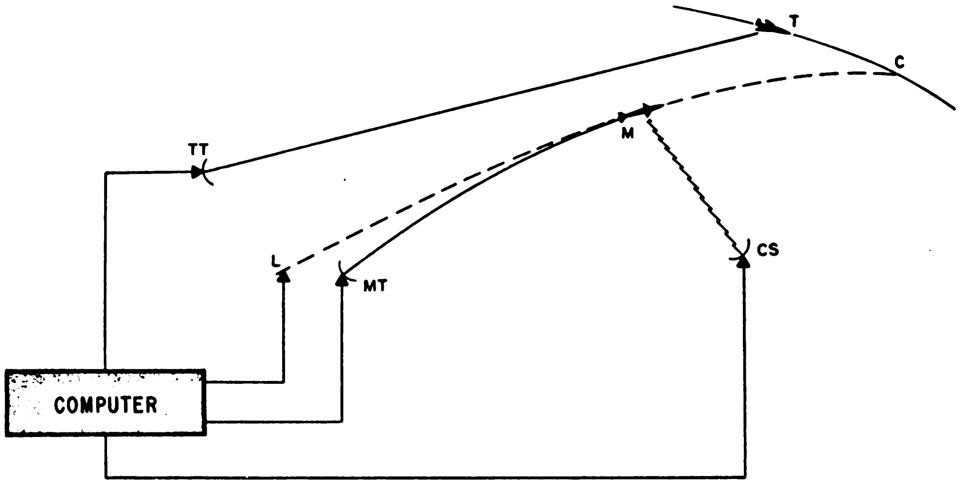

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Figure 3-34.—Typical command guidance system.

Remotely Guided Missiles

There are two types of systems within this category of remotely guided missiles, one in which the launching ship sends missile control orders via a data link to the missile, then uses a built-in missile flight path control mechanism to reorient itself; and one in which data is transmitted via a data link (guidance beam) to the missile which then determines its own flight path control orders. The first type of system is called a COMMAND GUIDANCE system, and the second type is called HYBRID GUIDANCE system. The most widely used HYBRID GUIDANCE system is the BEAM RIDER system.

COMMAND GUIDANCE.—In a typical command guidance system, illustrated in figure 3-34, two tracking radars are used to track continuously the target and the missile until intercept. The radar tracking the target provides the necessary target position data, while the radar tracking the missile provides similar data on the missile. On the basis of this data, the computer determines the missile flight path control orders necessary to maintain the missile on a flight path to intercept the target. The missile flight path control orders are transmitted to the missile by radar.

HYBRID GUIDANCE.—A second type of guidance, hybrid guidance, combines both command guidance and homing guidance to achieve many advantages of both systems. By maintaining the missile within the guidance radar beam and transmitting the data to the missile, the long range capabilities of command and semiactive homing guidance can be achieved. By having the missile compute its own flight path control orders, the entire mechanization of the fire control problem can be simplified, as it is in active and passive homing.

A common example of a hybrid guidance system is a beam riding guidance system. A transmitted RF beam is used to provide a direction to the target along which the missile must go. The missile must then determine its location with respect to the beam and must move to keep itself in the center of the beam. The equipment installed in the missile to perform these functions can be comparatively simple. By having the beam for guidance coincident with the line of sight on the target tracking beam, the missile will follow a form of pursuit course. By using a guidance beam which is made coincident with the target tracking beam at intercept, other flight paths can be used which will result in less stringent acceleration requirements on the missile.

WEAPON SYSTEM OPERATIONAL PHASES

The overall task of any guided missile fire control system may be generally described as e delivery of a warhead or payload, within e missile, to a target.

ARGET DETECTION

The target detection phase involves the sur-eillance and detection or discrimination of any nemy or unidentified targets that appear within e surveillance field. This detection is normally chieved by the ship's air search and surface earch radars, and in some cases by the ship's re control tracking radars.

ARGET CLASSIFICATION

This phase consists of classification of the etected target and identification. Identification f the target determines its friendly or un-riendly character.

To afford protection to friendly forces, IFF dentification Friend or Foe) electronic equip-nent is used in conjunction with the radar systems. hrough the use of IFF equipment, radar detected argets can be identified as friendly without esorting to verbal communications or visual dentification. An IFF transmitter emitts a signal n a particular frequency. The signal is received y the target in question and in turn transmits coded signal back to the ship. If the ship's eceiver is set to the particular coded pulse hain that is returned, it automatically signals e operators that the target is friendly. If no ignal is returned or the code is incorrect, e target is assumed to be unfriendly.

ARGET LOCATION

The target location phase consists of locating e target relative to the ship with sufficient ccuracy for effective weapon employment, and e maintenance of radar contact with the target.

Target location radars include those which ather the information necessary to define a rget's location for designation to the fire control ystem which will actually lock on and track e target.

Tracking is essential to target interception ince it provides the necessary flow of data ccurate bearing, elevation, and range) which s so important for target location. It may be ccomplished by two or more separate radars, which a search radar detects the target and ocates it with sufficient accuracy to supply formation to a designated fire control tracking adar.

A target can defeat a radar system in a variety of ways. Any countermeasure which gives false target information, such as chaff, and decoys can be effective since they tend to obscure exact target position and may cause an automatic tracking radar to "break track" and lose the target due to overloading the radar system with false targets. In these instances, the most effective counter-countermeasure is a highly trained operator and an accurate discerning device, built into the radar, that is capable of distinguishing false targets from real ones.

Jamming techniques are similarly effective because exact target position is lost and cannot be tracked in the jamming signal. Missile homing devices, radar receiver delay circuits, and random pulse repetition frequency of output are all effective methods of countering jamming techniques.

Spoofing with electronically simulated targets is also employed to overload and fool target tracking radar systems. Again, coding or randomness of radar outputs can successfully defeat this form of countermeasure.

MISSILE SELECTION

This phase involves selection of the optimum type of missile, consistent with the mission of the ship and its capabilities, and the designation of a specific fire control system to destroy the target. For example, in a guided missile cruiser, on detecting a threatening air target, the weapon control officer will select either a beam riding or homing missile and designate a specific guided missile fire control system to the target with that type of missile.

MISSILE LAUNCHING

The missile launching phase is concerned with the safe and effective launching of a missile into the desired flight path.

To fulfill the operational requirements imposed during the launching phase, a launching system performs certain specific functions; which are missile storage, transfer, loading and launching, figure 3-35.

The magazines and ready service stowage provide for the safe, protected storage of a supply of missiles needed to engage the enemy.

Transfer is accomplished by moving the missile from storage areas to the launcher.

Loading requires that the missile be moved from the transfer area to a position on the launcher. During loading and transfer, flight preparation of the missile is generally accomplished.

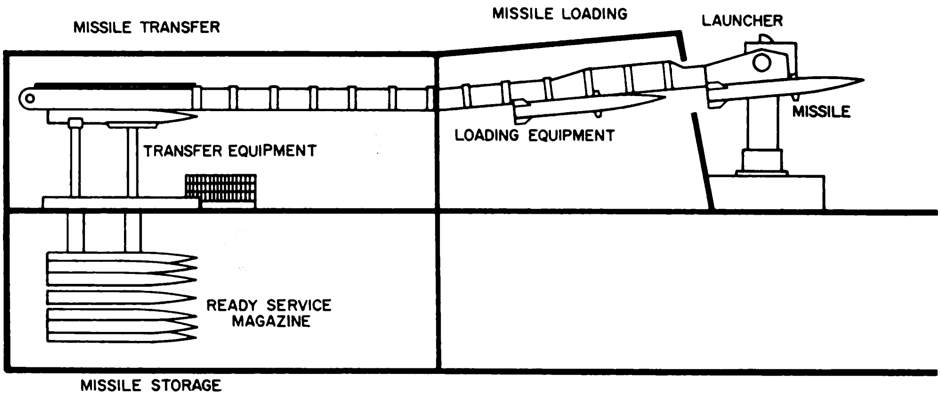

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Figure 3-35.—Missile launching system.

The fundamental unit of a launching system is the launcher which accomplishes flight initiation of the missile. Precision of launcher positioning orders at launch does not dictate the resulting kill probability of the target since the guided missile flight path is continually reoriented as the missile travels along its variable or controlled trajectory to the target. This is not to say that the launcher position on firing can be ignored. Most missile systems have correction and attitude control limits within which they must operate. The launcher must put the missile within these boundaries at launch or the missile's guidance system may not be able to compensate for the discrepancy and the gain control within the missile's guidance system.

MISSILE DIRECTION (GUIDANCE)

This phase consists of the acquisition of the target by the designated fire control system and the generation of the necessary missile control and guidance orders to intercept the target. Acquisition requires that a radar within the fire control system acquire and lock-on to the target in order to gather information pertaining to target position and motion. This information is processed in the fire control computer to generate missile control and guidance orders. The missile control and guidance orders define the orientation of the missile trajectory needed to destroy the target. This information is sent to the launching system for proper positioning of the launcher and the missile it contains, figure 3-36. The processing of target data and ballistic information factors is performed by analog or digital fire control computers.

Every missile guidance system consists of an attitude control system and a flight path control system. The attitude control system exercises control of the missile in roll, pitch, and yaw. It functions to maintain the missile in the desired attitude on the ordered flight path. The attitude control system of a missile operates essentially as an autopilot, damping out flight deviations that tend to deflect the missile from its ordered flight path. The function of the flight path control system is to determine the trajectory necessary for target interception and to generate the necessary orders for the attitude control system to follow.

Thus, the missile guidance system is essentially a fire control system and is inherently associated with the missile trajectory of flight path guidance phase. Therefore, when a guided missile is employed, the missile trajectory decisions continue to be generated either within the missile during homing or by the fire control computer during remote guidance after the missile has been launched.

Many of the guidance systems we discussed previously in this chapter may be combined to utilize the advantages of each system. For example, a surface-to-air missile may use preset guidance during the initial or launching phase to orient the missile in a radar beam, beam rider guidance during the midcourse phase, and homing guidance during the terminal phase, when the beam rider accuracy decreases.

PROBLEM SEQUENCE

We've already mentioned the sequence of operations that take place in the basic missile fire control problem. Let's plot these operations against a time base and compare their occurrence with the missile flight phases (fig. 3-37).

Detection operations are taking place during the period of time between T-1 and T-2. This period will vary depending upon the complexity of an engagement and operating conditions prevalent at the time. T-1 represents the time that target information is first disclosed. During detection, the target's approximate position is established and initial target evaluation takes place.

Designation occurs between T-2 and T-3. This represents the relatively short period of time that it takes to position the tracking radar to the approximate position of the target.

Acquisition, between T-3 and T-4, takes place after the tracking radar has accepted designation data from the data source (normally NTDS/WDS). Due to the narrow beam of the fire control tracking radar, the tracking radar may not see the designated target. The tracking radar is caused to scan a volume of space around the designated point in space. This should result in detection of the target and cause the tracking radar's automatic tracking circuits to come into operation.

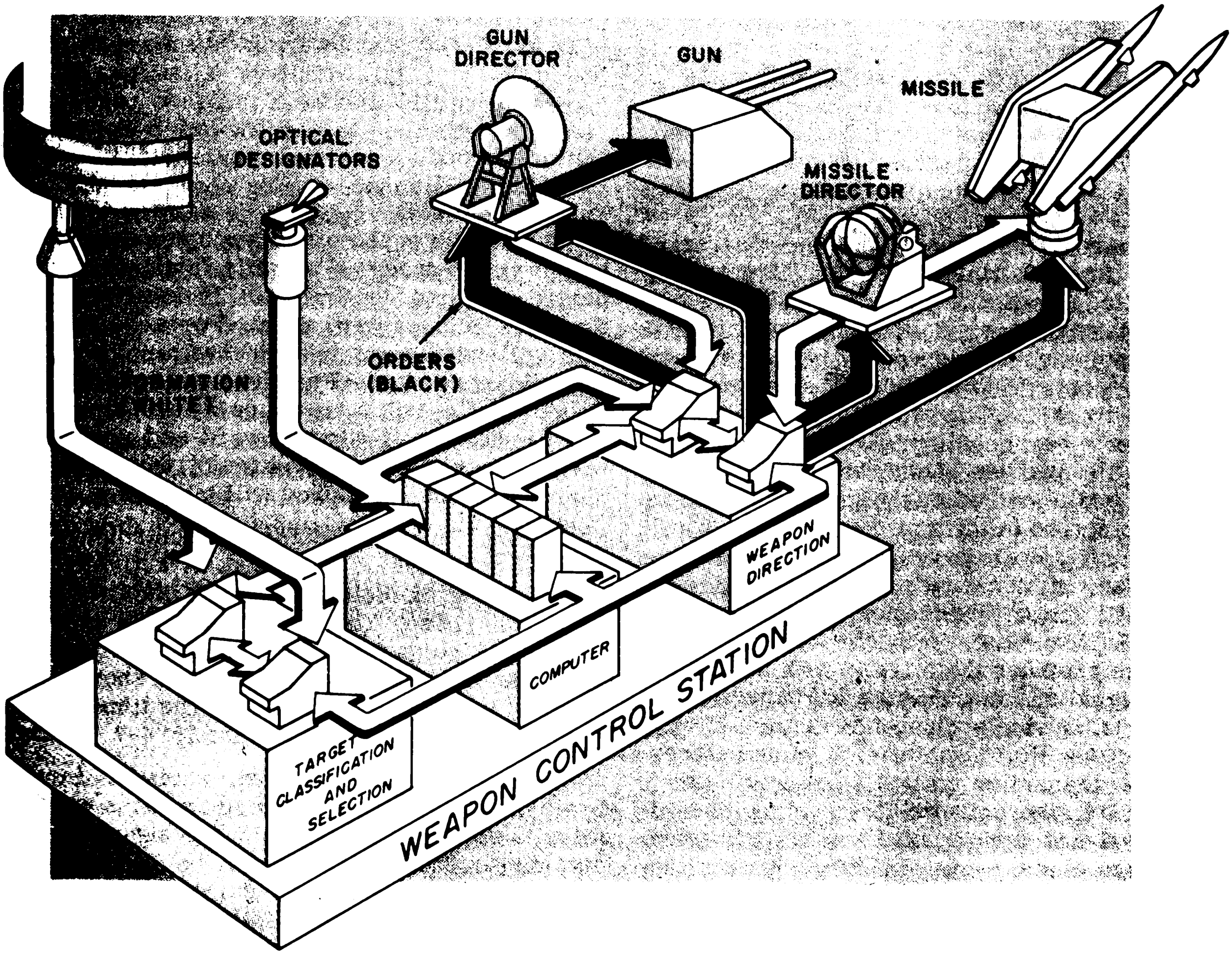

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Figure 3-36.—Weapon system operation.

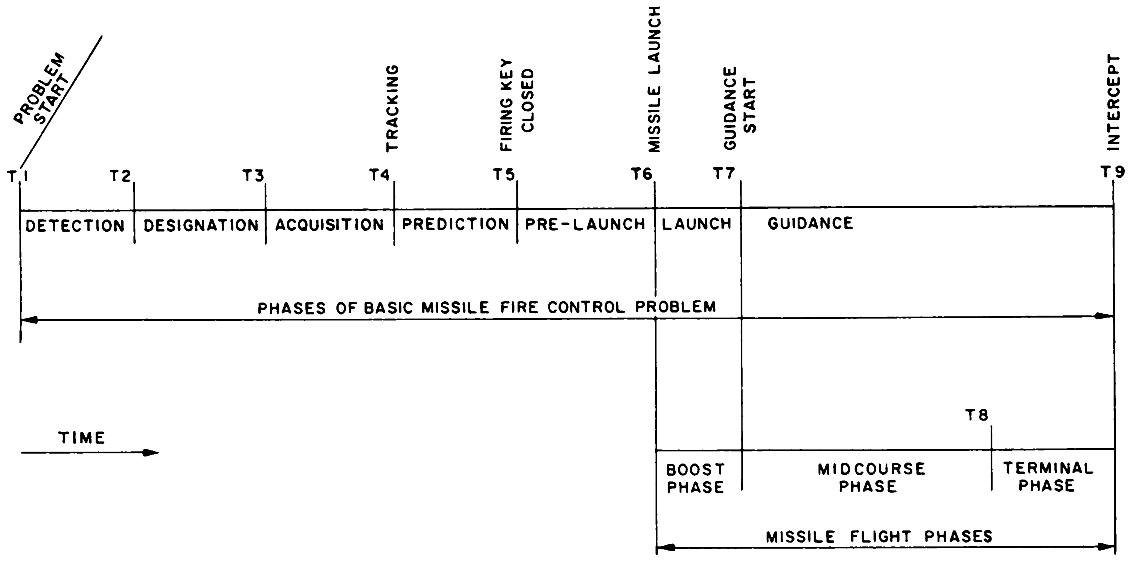

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Figure 3-37.—Problem sequence.

T-4 represents the time that automatic tracking starts. At this time, accurate target data is transmitted from the tracking radar to the fire control computer. Based upon this target data, the computer starts computing prediction and launch data. The prediction data will be transmitted to NTDS/WDS for a final evaluation of the target's engageability. Launch data computations will provide launcher position data which will be transmitted to the missile launcher when it is assigned to the appropriate fire control system.

Evaluation of a target's engageability will continue until the determination has been made to fire. At this time, T-5, the firing key is closed. This provides the missile with an intent-to-launch signal and initiates the prelaunch phase of operations. During prelaunch, the missile will be brought to a flight operational status. When the missile transmits "missile-ready-to-fire" to NTDS/WDS, the missile firing circuits will be completed and ignition of the missile booster squibs takes place. This, in turn, ignites the missile booster and missile launch occurs at T-6. Prelaunch operations involve less than 2 seconds of time.

The launch phase of our problem corresponds to the boost phase of missile flight. During this period of time the missile is in flight and on its way to a capture point. For a beam rider, this will be a point in space within the capture or guidance beam. For the semiactive homer, it will be a point in space where the missile seeker head will slew toward and acquire the target. In any event, capture of the missile by a remote guidance source will take place.

During launch the missile control surfaces may or may not be activated. If activated, they are striving to maintain missile stability during the boost phase. You can look at this as a form of missile guidance. However, for our problem, guidance is going to begin at T-7, shortly after booster burnout or separation. The time between T-6 and T-7 is approximately 4-7 seconds.

As already established, guidance for our basic fire control problem commences when the missile starts receiving guidance signals from an outside source. Guidance will be in effect until intercept (T-9). The time duration of guidance, assuming a constant missile velocity, will be dependent upon intercept range.

CHAPTER 4

MISSILE SYSTEM TESTING

One of your primary responsibilites as a rated Missile Fire Control Technician will be the supervision of your men in their duties with respect to missile system testing. To lead your men effectively in their work, you must know the proper procedures for operation and maintenance within this subject area. Detailed step-by-step procedures must be obtained from the technical manuals available on your ship or station. This chapter, however, will provide you with knowledge that will assist you in the analysis of these step-by-step procedures.

Secondarily, you will be concerned with the handling of missiles. Although missile handling is performed by Gunner's Mates (Missile) (GMM), you are not relieved of the responsiblity of being able to recognize unsafe conditions due to mishandling. For this reason alone, it is important that you understand the basic missile handling procedures. In this chapter, we will first present a brief coverage of missile handling. After this, we will discuss some of the more important aspects of missile testing.

After completing this chapter, you will be familiar with the procedures of missile handling ashore and afloat. You will acquire knowledge concerning the techniques of determining a missile's operational capability by means of missile testing.

MISSILE HANDLING

Missile handling refers to all procedures and steps taken with missile components from the time they leave the factory until the missile is launched. Figure 4-1 illustrates the flow of missile components from the manufacturer, on to a designated Naval Weapons Station (NWS) which has missile assembly and servicing facilities, and finally to the firing installation in the form of a complete missile.

As a Missile Fire Control Technician, you will be concerned with two phases of missile handling—Naval Weapon Station handling and shipboard handling. The handling methods used at these two locations will differ extensively due to the differences in space availability and the missions of the installations.

NWS HANDLING

The Guided Missile Maintenance Division (GMMD) at a Naval Weapons Station has the responsibilities of receiving, inspecting, assembling, testing, and issuing missiles to the firing installations. Usually, complete missiles are not sent from a manufacture to the GMMD. The prime contractor for a particular missile sub-contracts certain sections of the missile to other manufactures (subcontractors). Most prime contactors receive all subcontracted sections at a central location, usually their factory, and they do the distributing to NWS. At NWS, the missile sections are unpacked, inspected, serviced, and tested.

Other jobs performed by the GMMD are igniter testing, fuze testing, and shipping container maintenance. Stockpiled missiles are retested at periodic intervals and inspected for corroded and over age components. Humidity level in missile containers is checked weekly and the desiccant changed when necessary. (Containers and desiccants will be discussed later in this chapter.)

Missiles returned to the GMMD from firing activities must be closely inspected for damaged or unserviceable components before placing them in the retest and issue cycle. Damaged components and sections which cannot be repaired at the GMMD are returned to a repair activity or disposed of in accordance with Naval Ordnance (NAVORD) instructions.

GMMD Handling Equipment

Each piece of handling equipment at the GMMD is designed specifically for one function. It will be used for the task for which it was designed

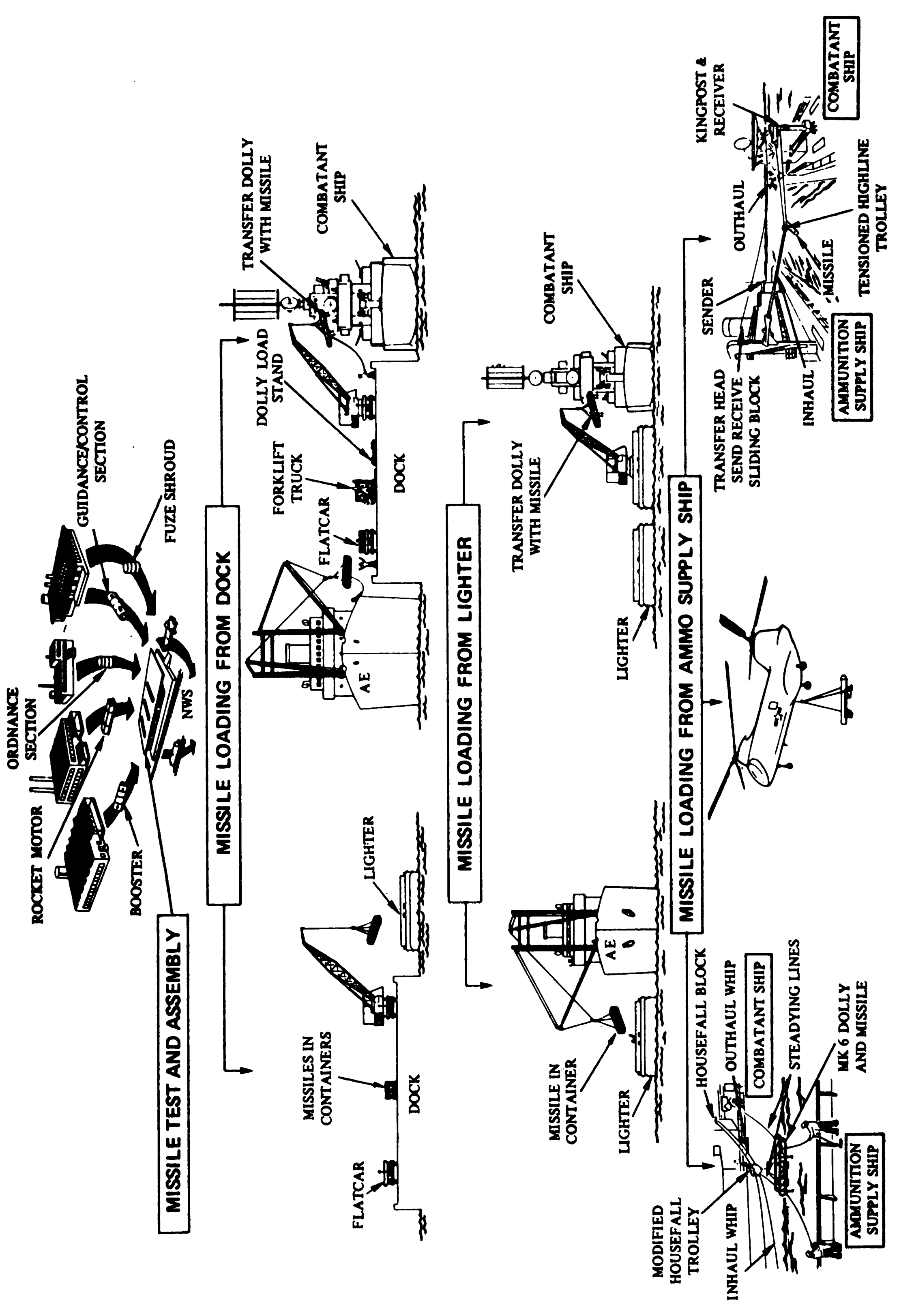

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Figure 4-1.—Flow of missile components.

and no other. For example, a warhead carrier, if used to lift a complete missile, would probably fail and drop the missile, possibly causing detonation of an explosive or at least extreme structural damage. The GMMD is provided with all necessary container slings, missile-lifting slings, test stands, and special lifting devices for carrying the various missile sections. Overhead cranes, birail trolleys, and chain falls are more examples of GMMD handling equipment.

Different missile systems have specially designed handling equipment. Attempting to work on one missile with equipment designed for another can only lead to damage to the gear and possible injury to personnel.

Shipping Containers

Missile components are shipped from various manufacturers to NWS in many different types of container. From NWS, complete missiles are shipped to firing installations in varying types of missile containers. Missile containers must be designed with certain factors taken into considerations such as:

1. SECURITY. The container must protect fragile missile components from humidity, vibration, static electricity, rough handling, and tampering. Since most missile components have a security classification (Confidential or Secret), they must be completely enclosed in the container.
2. EASE OF HANDLING. The container must be of size, weight, and shape that will allow handling by slings, fork lift, or other similar methods employed ashore or afloat.
3. ACCESSIBILITY. The containers must be easy to open and the contents readily removable.
4. SAFETY. Missile containers must conform with applicable Navy safety precautions and Coast Guard shipping, storage, and safety precautions regarding explosive and flammable material. Overland shipment of missiles by rail or truck introduces the requirement of conforming to Interstate Commerce Commission regulations concerning transfer of explosives and flammables.

The missile containers used by the Navy meet the above requirements, except in some cases where handling or accessibility is sacrificed for absolute safety and security. Safety and security are never sacrificed.

The primary function of a missile container is to protect fragile missile components from damage during storage and handling. Therefore, most containers are of sturdy metal construction with some type of internal cushioning for the prevention of damage to contents by shock or vibration. Containers may be pressurized if it is desired to keep the missile components in a constant atmosphere, or kept at atmospheric pressure if a controlled atmosphere is unnecessary. All missiles or missile components are packed with a desiccant (dehumidifier) included in the container and humidity indicator to show interior humidity. The desiccant and indicator are very often treated silica gel crystals which will turn from blue to pink with increasing humidity. Some containers have a guide which indicates the humidity within the container according to the shade of blue or pink of the indicator. If the humidity in the container rises above an acceptable level, the desiccant may be heated or baked to dry it out. When this is done, the silica gel crystals assume the original blue shade.

Provisions are also made to ground missile components to the container to prevent buildup of static electrical charges. Large containers are provided with skids for stacking, fork-lift cutouts, and fittings for lifting with slings.

A typical cylindrical pressurized container is shown in figure 4-2. The missile is placed in rubber shock-mounted saddles and is then rolled into the container on a track and held in place by locking bolts through the outside of the container into the saddles. (It is important to remember when working with a pressurized container to bleed off the air pressure before removing the cover. Even relatively low pressures may cause the cover to be blown off if the cover bolts are removed before bleeding the container.)

The most common type of guided missile container now used in the Navy is the box or "coffin" style shown in figure 4-3. This is normally a non-pressurized container which is vented to the atmosphere through breather valves. The cover of the container is held down by trunk type latches and is made weather tight by an inflatable gasket. The missile or missile component is supported by handling bands which are installed before placing it in the container. The handling bands provide the means of lifting the missile, and, by fitting into guides on the inside of the container, also prevent movement of the contents during shipment. The packaged missile is cushioned by sponge rubber pads attached to all inside surfaces of the container. Missile containers should not be stacked more than three high.

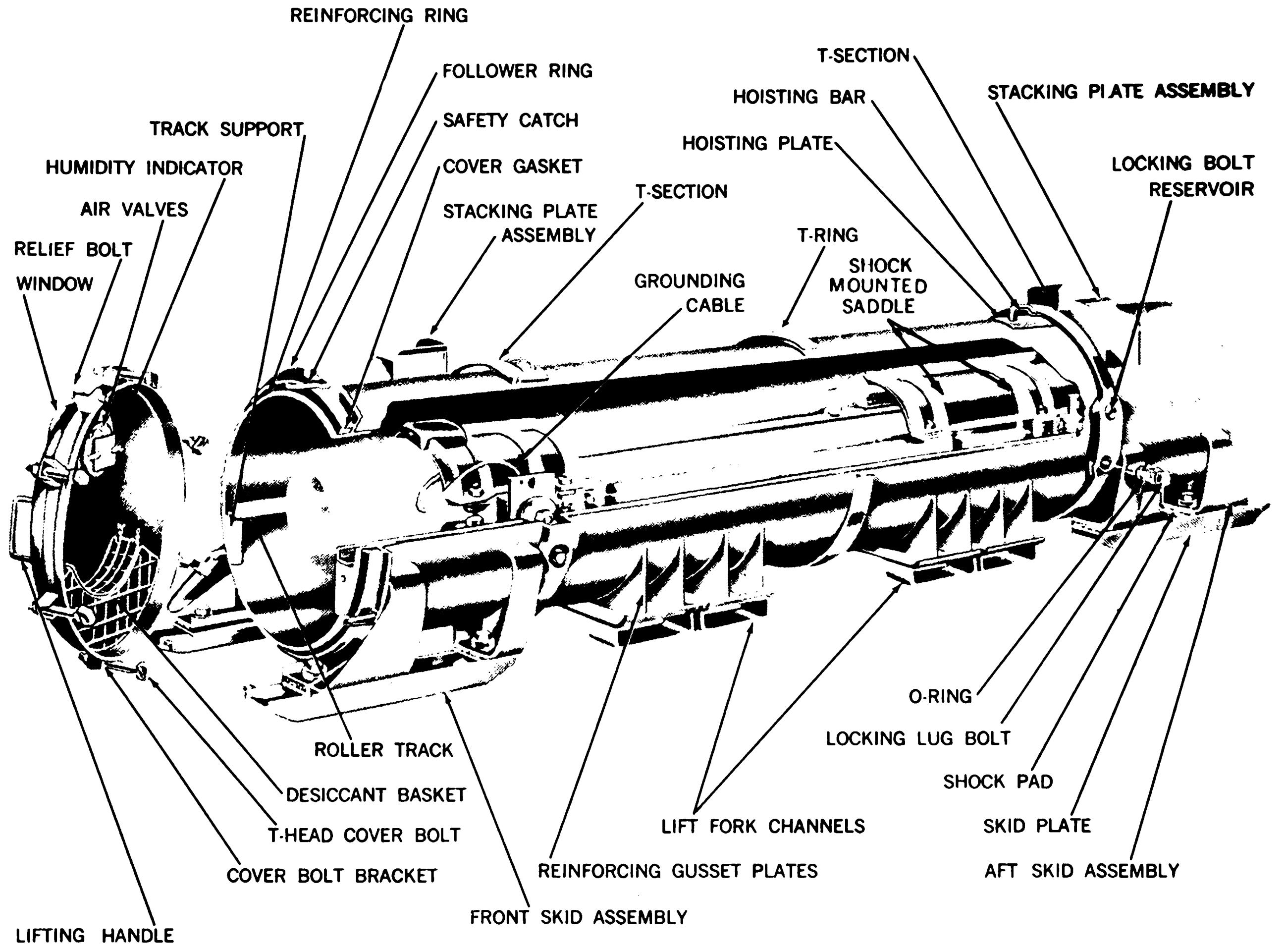

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Figure 4-2.—Missile shipping container.

Most missile ordnance items are shipped in various sizes of steel drum containers. These are standard drums with rubberized hair cushioning, shaped to encase the component being shipped. The cover is secured with a tension ring. The steel drum container affords maximum protection for explosives, and yet is simple, inexpensive, and readily available.

All missile containers are reusable and therefore must be maintained in good condition. Containers which are simple in construction require little maintenance. Some containers are elaborately built and require an inspection and maintenance program, which is outlined in the Ordnance Pamphlet (OP) furnished with the equipment. A periodic inspection usually includes a check of all sealing surfaces, support fittings, threaded surfaces, and overall condition of the container. Required maintenance should be performed at the time of inspection and is normally carried out at the GMMD.

Special Tools

Each missile activity is furnished a special tool kit for each type of missile. These tools are used to assemble, disassemble, maintain, and repair missiles and missile components. Since they are not standard tools they cannot be readily replaced from general stores. For this reason, extreme care must be taken to prevent their loss or damage.

Many missile components do not have standard hardware (nuts, bolts, etc.). Therefore, it is

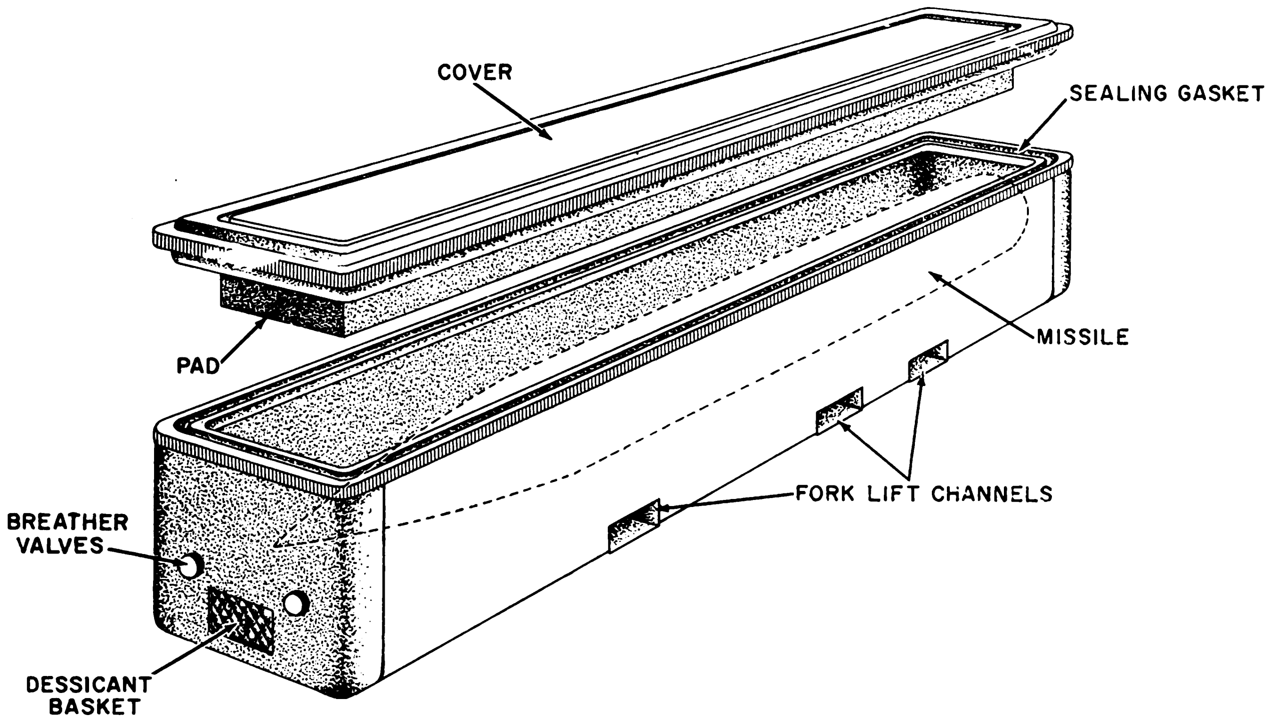

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Figure 4-3.—Coffin style container.

absolutely necessary to have the correct tool before any work can be done on a particular component.

As you know, guided missiles experience extremely high accelerations during flight. These cause larger forces on the missile structure, especially at the joints where sections are mated. This presents the requirement of tightening the bolts between missile sections to exact torque values. TORQUE WRENCHES are used exclusively throughout the missile field to ensure proper settings.

Also included in the special tool kit are ARMING TOOLS for explosive arming devices that cannot be armed with standard tools. Tools made of nonsparking metal are provided for working on explosive components in the missiles. No other tools are to be used on ordnance items. The nonferrous metal used in these tools is soft and will not withstand rough treatment or application of high torques.

One example of a specialized tool is the CLINOMETER, an instrument equipped with a leveling device which is used for measuring values of the angle made by a control surface and a reference plane. Various kinds of clinometers are employed for checking and adjusting missile control surfaces. Because of the differences in airframe configurations of the various missiles, each of these instruments must be used in accordance with instructions appropriate for the particular measurement involved.

Less specialized measuring tools are also required in the everyday duties of the Missile Fire Control Technician. At various times modifications of missile units and assemblies must be made; and the layouts must conform exactly with specifications given in the prints or drawings accompanying the modification orders. Among the measuring tools used in most cases is the ordinary DECIMAL RULE. VERNIER CALIPERS may be required for more precise measurements.

THICKNESS GAGES are needed for many adjustments made in hydraulic and pneumatic units, for example, when repairing a hydraulic servosystem. This type of tool is necessary for operations such as setting the travel distance of valves, which in typical cases are adjusted to tolerances such as ± 0.002 inch.

Vernier calipers, micrometer calipers, thickness gages, and most of the basic measuring tools used in missile work are discussed in Tools and Their Uses, NavPers 10085-B.

It is important that the tools in your working area be kept in good condition at all times by ensuring that they are clean, free from rust and corrosion, and in their proper place. It would be difficult, if not impossible, for your men to do their job with equipment and tools not in proper working condition.

SHIPBOARD HANDLING

A Missile Fire Control Technician aboard ship will be concerned to some extent with two missile handling functions. The first of these involves transporting a missile back and forth between its stowage location in a magazine and the location where the testing and repairs are performed. The second function is replenishment at sea. Although you may or may not play a leading role in missile handling, it is certainly important that you understand what is going on in this regard.

Most missile handling aboard ship is done by the automatic equipment of the launcher-loading system. This equipment is operated by the GMM's responsbile for the launching system. They will bring missiles from the magazine and deliver them to the testing crew in the missile testing area. The testing crew will make all test connections to the missile and ensure that all safety precautions are observed during the entire operation. After testing has been completed and corrective action taken (if necessary), the testing crew will disconnect the missile from the test set. The missile will then be returned to the magazine by the GMMs.

Replenishment at Sea

Replenishment at sea may be accomplished by means of any one of four transfer methods.

1. The Burtoning method.
2. The constant tension highline method.
3. The modified housefall method.
4. The Standard Tensioned Replenishment Alongside Method (STREAM).

We will cover only the modified housefall and STREAM methods because they are the methods most commonly used in the fleet.

Modified Housefall

The modified housefall rig is shown in figure 4-4. Completely assembled missiles and boosters (less wing and fins) are removed from their containers, suspended in a transfer dolly (called a grasshopper) and transferred from the ammunition ship to the missile ship. Missiles or boosters arrive on the 01-or 02-level (depending on the type of ship) atop the deckhouse at a point near one of the strikedown hatches. To maintain a simultaneous port and starboard flow, missile-booster transfer is scheduled so two boosters are transferred, followed by two missiles. Scheduling of missile component transfer is arranged so that a balanced group of components will have been transferred in a given time. This is done because missiles and boosters have to be mated on the receiving ship before they can be stowed in a magazine. You have to mate a missile to a booster before you can receive the next two in the missile house. That's why they are received in the order as follows: booster, booster, missile, missile. Normally, both port and starboard strikedown hatches are used. Spare warheads and exercise heads are also transferred on the modified housefall rig. The transfer cart or dolly is also used for inner missile house transfer between rails.

The highline shown in figure 4-4 is used to to transfer missile components such as wings, fins, and spare parts concurrently with booster and missile transfer.

The above method of missile transfer is used only if the STREAM system is not installed.

STREAM Method

The STREAM method transfers missiles and components to combatant ships equipped with special receivers formerly known as FAST receivers.

The STREAM method maintains control in the movement of missile components from storage on the delivery ship through the intership transfer and through the strikedown operation on the combatant ship. Proper use of STREAM will ensure delivery of "go" missiles; will reduce alongside time, deck handling, and hazard to crew; and will increase heavyweather replenishment capability.

The missile STREAM receivers installed in combatant ships are of two basic designs — the TARTAR/TERRIER receiver (fig. 4-5, view B), and the TALOS receiver (fig. 4-5, view A).

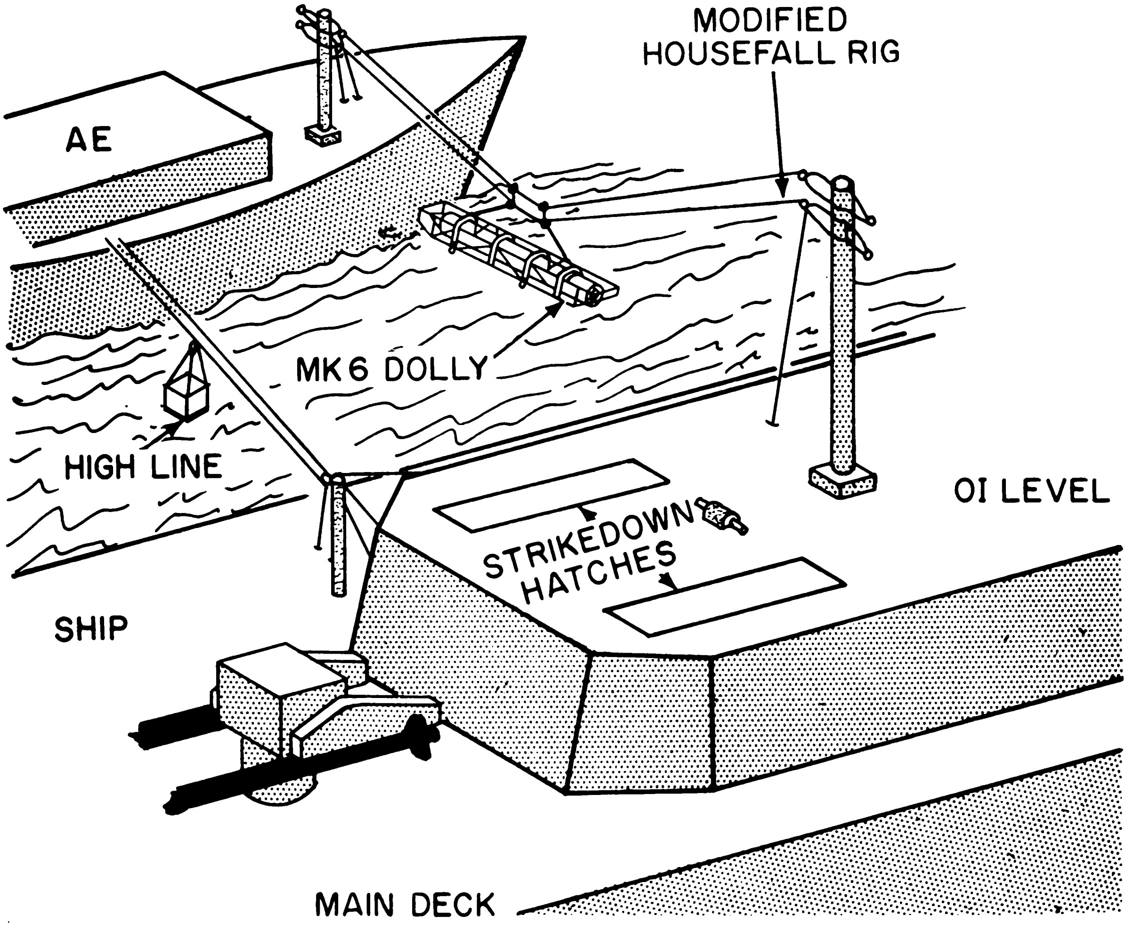

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Figure 4-4.—Modified housefall method of transfer and replenishment at sea.

Vertical Replenishment

Vertical replenishment (VERTREP) promises to be an ideal transfer method for missiles. The helicopter can lift the missile high above the sea spray associated with connected transfer methods. The ability of the helicopter to hover at a precise position or altitude reduces the danger of damage to the relatively fragile missiles as it arrives aboard the ship. Two methods of missile VERTREP are currently used, the choice being dictated by the strikedown method employed aboardship. In the first method, missiles and boosters are carried in containers and are decanned at the strikedown equipment. In the second method, missiles are transferred in a missile dolly, figure 4-6. The dolly can be transported by fork-lift truck, manhandled on castered wheels, or lifted by its sling. It is constructed of tubular steel and provided with a dead man brake system, shock absorbers on each wheel, and fold-down side bumpers. It provides mobility and shock protection during VERTREP of TERRIER missiles, TERRIER boosters, and TARTAR missiles. When adapted to carry the TARTAR MR missile, the dolly interfaces with the TARTAR launcher for strikedown of the missile.

The TARTAR ER missiles or boosters are loaded aboard by means of a crane and lifting beam (from dockside). The lifting beam is attached to the handling attachments on the missile or booster. The crane lifts the ER missile or booster out of the container and places it on the ship strikedown elevator for strikedown to the ship magazine. Transfer-at-sea from ammunition

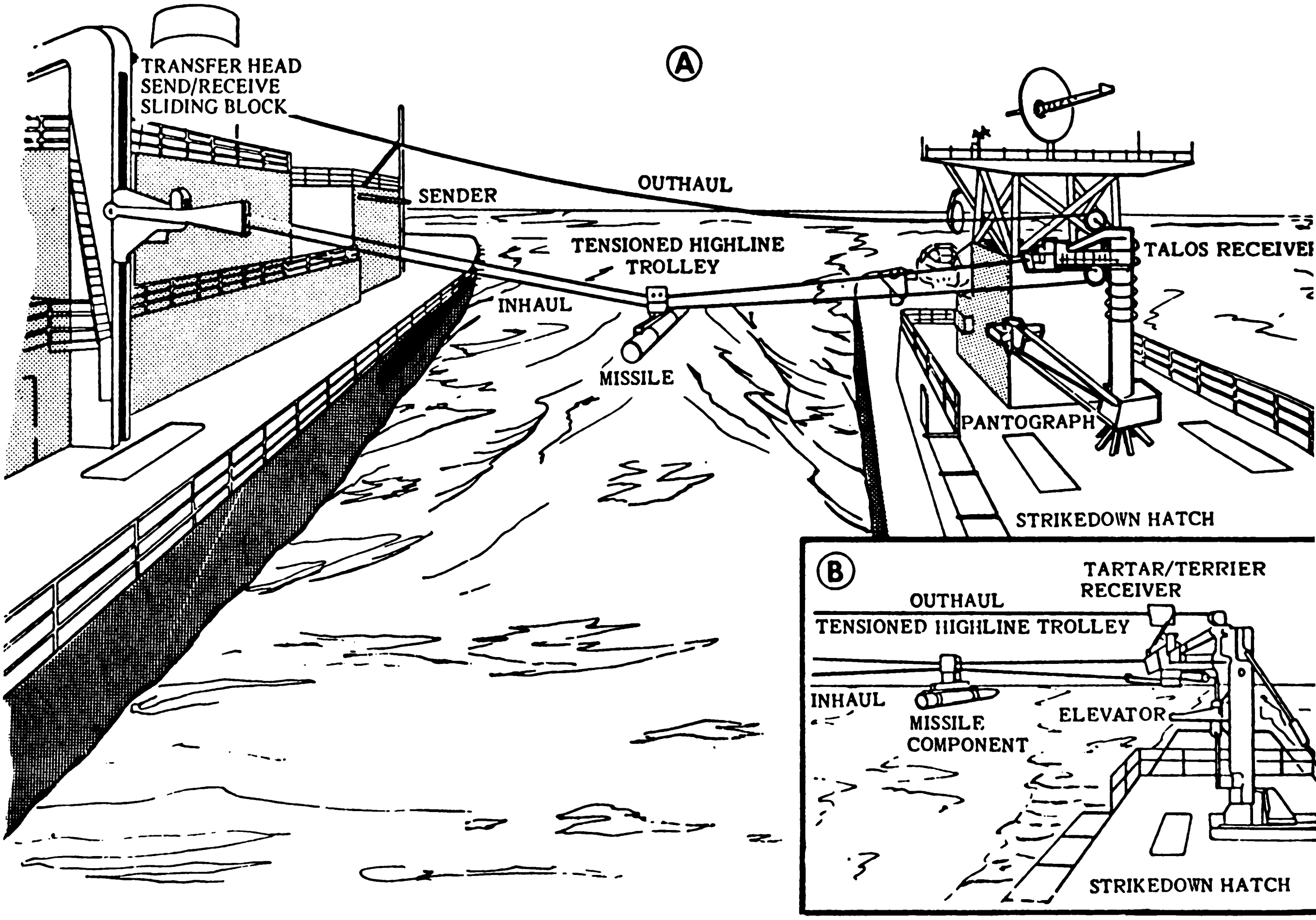

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Figure 4-5.—STREAM method of transfer and replenishment at sea.

ship to a combatant ship is accomplished by the modified housefall, vertical replenishment (VertRep), or Ram Tensioned Highline (RTHL).

MISSILE HANDLING PRECAUTIONS

When involved in missile handling, you must ensure that approved local safety regulations (whether aboard ship or elsewhere) are carried out to the letter. Detailed precautions must be observed, and specific instructions must be followed with each type of guided missile. These are given in the technical publications pertaining to a particular missile.

Basic Precautions

You must see that work areas are kept clear of obstructions, loose cables, hose, and unneeded equipment during missile assembly and testing. Only those persons engaged in the work in progress should be permitted in the work area or in the vicinity of the missile at these times.

Be especially careful around explosive units. All rocket motors and explosive units must be handled in strict accordance with standard Navy practices for ordnance materials.

Use only authorized handling equipment for missiles, missile sections, components, shipping crates, and containers. Also be certain that all electrical equipment used in missile handling operations is adequately shielded and grounded to prevent electric shock.

During crating and assembly operations, be careful of sharp edges which are often present on nose assemblies, wings, and tail fins. After assembly, all dangerously sharp edges should be covered with guards. Tools used for uncrating

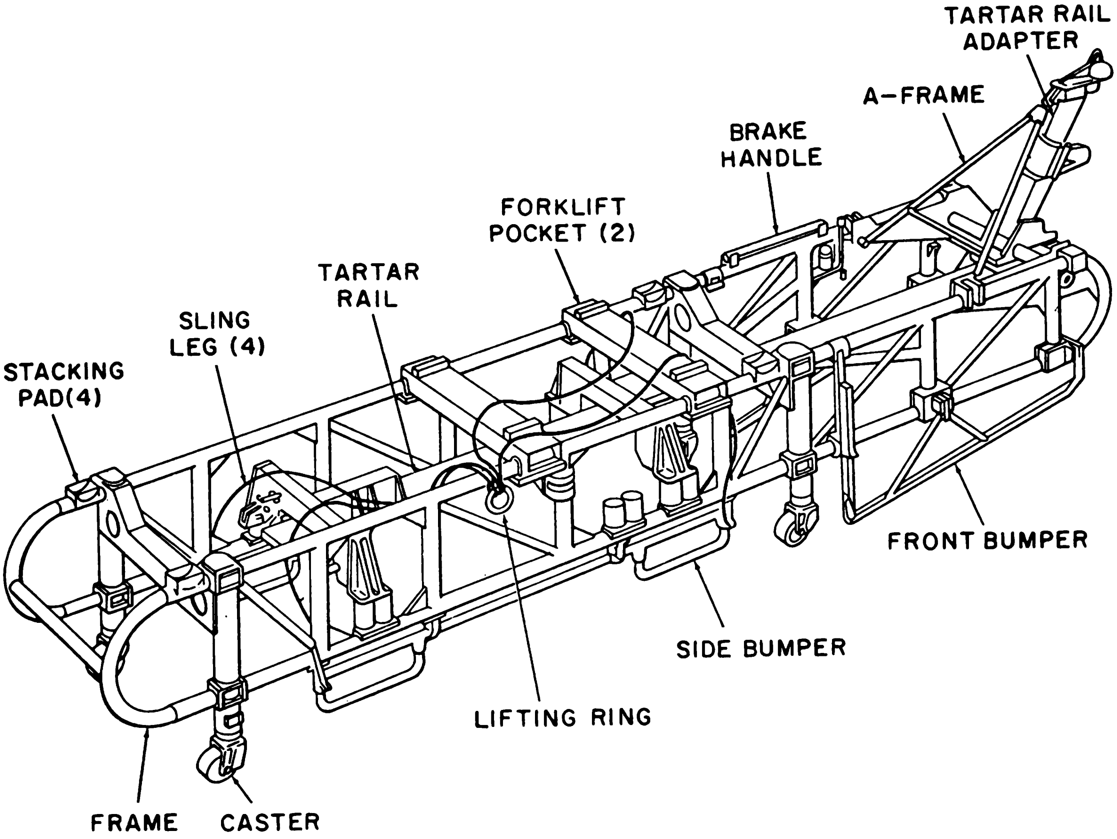

Figure 4-6.—Tartar/Terrier transfer dolly.

missile components during assembly must be of the type specified in the missile handling OPs. Never attempt to force any unit. If a unit does not fit properly, determine the cause and correct it before proceeding.

Missile Handling Dos and Don'ts

- Be sure all arming indicators are SAFE.
- Keep loaded metal containers grounded.
- Make sure slings, hooks and handling bands are installed properly and at their proper locations.
- Return any missile that has physical damage or an expired service date.
- Return any container of explosive items that has been dropped 5 feet or more.
- Do not bypass safety devices at any time.
- Do not onload missiles and boosters faster than they can be struck down.
- Do not remove guardrails while rounds are being moved into or out of magazines.
- Do not release missile, booster, or weapon from one piece of handling gear until positively secured in the receiving handling gear.
- Do not unpack explosive components if the container has been dropped or if the container has sustained excessive damage.
- Do not store boosters with the forward end lower than the aft end.

GUIDED MISSILE TESTING

The TARTAR, TERRIER, STANDARD, and Point Defense missiles are considered as "wooden rounds" and are not tested aboard ship.

Even though you may find yourself in a NO-TEST environment, this will not eliminate your need to understand missile testing concepts. All missiles are tested at the designated Naval

Weapons Station (NWS) prior to transfer to the fleet.

GUIDED MISSILE TEST SET

Special test sets have been developed for each specific missile system. The Guided Missile Test Set (GMTS) programs the missile through a simulated flight sequence, comparing missile response to known standards. A missile systems test is made up of a number of individual tests of the different circuits in the missile. The final result of the test is a GO or NO-GO indication of missile overall condition. Light indications are used to determine the passing or failing of specified test. A GO indication at the end of a test means the missile is flight-ready. A NO-GO condition indicated by the fault lights shows the missile failed the test. The particular lights involved designate which assemblies in the missile should be repaired or replaced. After correcting the discrepancies, the missile is retested.

CONDUCT OF TEST

The test is accomplished by sending a predetermined sequence of simulated control and guidance signals, in the form of radar energy, to the beam-rider or homing sections. These radar signals produce correction signals in the missile which will cause the missile to respond. By picking off the outputs of various circuits, it can be determined easily whether or not the control surfaces are responding correctly to the known input signals. This process of comparing the actual results against expected results is referred to as "open loop" testing.

GMTS SECTIONS

For explanatory purposes, the Guided Missile Test Set (fig. 4-7) may be broken down into four sections:

1. Signal generator
2. Program section
3. Evaluation and indication section
4. Power supply section

(The test set components to be discussed are typical of those you will use, but should not be considered representative of a GMTS for a specific missile. The description and operation of the GMTS for your particular system should be obtained from the technical manuals at your station.)

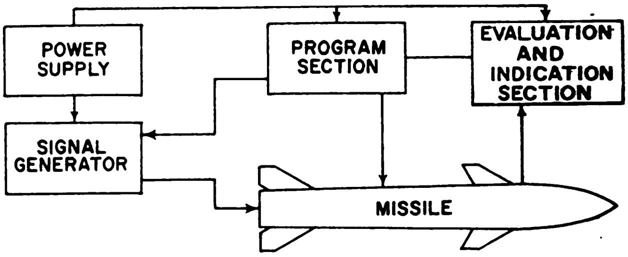

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Figure 4-7.—Guided missile test set.

Signal Generator

The signal generator section of the test set is controlled by the program section. It provides a simulated radar beam like the one which the missile would normally receive during flight. This simulated radar signal is identical to the missile guidance radar output except that the simulated signal has a lower power level. To produce error signals in a beam-rider missile the radar energy is amplitude-modulated in various AM/FM phase relationships so that the missile can be tested under more than one error condition.

Errors are developed in homing missiles by applying the radar signals at different angular positions with respect to the homing antenna system.

The signal generator of the GMTS for a beam-rider missile must simulate the output of a pulsed radar. The pulse generator produces frequency-modulated video pulses which are fed to a modulator tube. RF energy from a klystron is also fed to the modulator and is modulated by the pulses. Amplitude modulation of the output can be obtained by varying the bias on the modulator tube at the desired rate. Different phase relationships of the amplitude and frequency modulations of the pulses will simulate various missile angular position errors. The amount of amplitude modulation can be varied to simulate different missile distances from the radar beam nutation axis.

Homing missiles must also be provided with radar signals similar to those which the missile would normally receive in flight. Continuous wave RF energy is frequency-modulated to produce the desired effect. A number of different modulating frequencies are used in the test set to simulate various target closing rates to the missile's homing seeker. The missile control system should respond as it would in flying to intercept a target.

The signal generator also feeds signals into the missile which simulate accelerometer and gyro outputs which could normally be expected in flight. Since these instruments are not actually displaced during testing, the simulated signals are used to check the responses of their associated circuitry.

Program Section

The program section of the GMTS controls the operation of the testing equipment and missile during tests. The programmer itself may be a bank of cam-operated microswitches, a tape reader, or tape transmitter. In any case, the programmer energizes relays at certain times during the test, activating missile and test set functions in a predetermined sequence. The test set functions may be in the program section, signal generator, or evaluation and indication section.

The programmer controls itself in that it starts, stops, and resets automatically in accordance with its own signals.

In the signal generator, the program section controls such things as:

1. Selection of the amount of amplitude modulation of the RF pulses to the beam-rider receiver.
2. Selection of various AM/FM phase relationships of the RF signals furnished the beam rider.
3. Selection of various FM signals used to produce different closing rates for a homing seeker.
4. Cutting in and out simulated gyro, accelerometer, and other signals to the missile.

The program section controls the following test functions in the evaluation and indication section:

1. Selection of the missile signal to be tested.

2. Selection of signal attenuation.

3. Setting up high and low tolerance voltages for the comparator.

4. Sequence of test and reset of circuits for each individual test.

Missile functions controlled by the program section are:

1. Cutting in and out power to the missile.
2. Energizing and denergizing relays in the missile in the proper sequence.
3. Completing various circuits in the missile at the appropriate times.

Evaluation and Indication Section

The evaluation and indication section of the test set provides indications of the test results. The results are displayed by On-Off test (fault) lights. If there is more than one test associated with a particular fault light, all must pass successfully to get a GO indication. For example, a beam-rider receiver is tested under numerous AM/FM phase relationships which control one fault light. Each one of these tests must pass within set tolerances or the light will indicate that all failed.

The test set evaluator is made up of a relay-controlled limit voltage selector and a comparator. High tolerance and low tolerance (limit) voltages are fed to the comparator along with the missile signal being tested. If the signal voltage remains within the two limit voltages, the comparator will provide a GO indication to the indicator section. If the test fails, the comparator will send a signal to the indicator section which will cause a NO-GO indication.

The evaluation and indication section is also provided with an electronic (vacuum tube) voltmeter for monitoring missile or test set voltages. The test set can be controlled manually so that selected missile signals may be read on the voltmeter. The meter is a valuable aid in troubleshooting the missile and the test set.

Power Supply Section

The power supply section furnishes the required power for operation of the GMTS. The critical d-c voltages must be regulated, and the alternating current must be frequency-stabilized. Adjustments are provided on the power supply units to meet these requirements in daily checkout procedures.

FUZE TESTING

As you know, many missiles use radio proximity fuzes to detonate high explosive warheads. These fuzes are fragile and must be tested upon receipt at the GMMD to determine whether they were damaged in shipment from the manufacturer or the launching installation. The GMMD has a fuze tester for each type of fuze handled. Fuzes are also tested with the GMTS at the launching activities as one of the functional tests of the missile.

At the GMMD the fuze is given continuity checks, a static test, and a dynamic test. Continuity and resistance checks are performed on various pins of fuze connectors to ensure that all circuits are complete. The static test checks voltages at pin connections with the fuze energized. For the dynamic test; a target simulator generates signals similar to those which the fuze would sense during an actual flight.

Fuze cables are checked for shorts and insulation breakdowns with a megohmmeter. This check is important as a short circuit could cause the fuse to activate prematurely and detonate the warhead before time of intercept.

The GMTS aboard ship can also be used to check a few of the more important voltages and currents in the fuze under static conditions. If the fuze fails any of these tests it should be replaced. Faulty fuzes should be returned to the GMMD for disposal. For ease of maintenance, a service log accompanies each fuze from the time it leaves the manufacturer until it is expended. Each activity that handles the fuze is required to fill in the log when a test is performed on it.

GENERAL PURPOSE TEST EQUIPMENT

In addition to specialized missile test devices, numerous types of general purpose instruments are used by Missile Fire Control Technicians. Some of these equipments are used in conjunction with the GMTS, while others may be used independently. This equipment consists mainly of electronic and electrical test sets and meters. General purpose test equipment will be covered in chapter 12 of this training manual.

GMTS SIGNAL CHARACTERISTICS

The signal generator of the GMTS provides signals that are representative of the signals that the missile is expected to receive in flight. The missile will respond to these signals when they are applied in the appropriate manner. In order to obtain the proper response, which will be carefully measured, the missile, GMTS signal generator, and the guidance radar must be in accord with respect to frequency, phasing, and coding.

Obviously the missile must be capable of receiving the transmitted frequency of the guidance radar. Just as obviously, the signals produced by the GMTS signal generator must be at the same frequency.

SYSTEM OPERABILITY TEST

System operability test are conducted on a daily basis (DSOT) to assess the readiness of the weapon control system to complete a successful engagement. During the tests, a significant amount of equipment and system alignments are checked. For the most part, the checks are accomplished by observing summary or end-point indications. This method enables the validation of many parameters with a minimum number of observations. Should an error be detected during the tests, fault isolation procedures are followed to localize the problem to either a piece of equipment or to an interface.

TARTAR OPERABILITY TEST

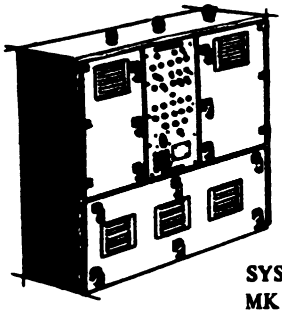
The TARTAR DSOT refers to a semiautomated test which uses special instrumentation to challenge the system, to compare the response to a standard, and to identify those responses that are beyond the predetermined acceptable limits.

The TARTAR DSOT is a coordinated exercise of the weapon system employing the same sequence of operations found in an engagement. The time required to perform a DSOT is under 30 minutes and will evaluate systems performance in the following areas:

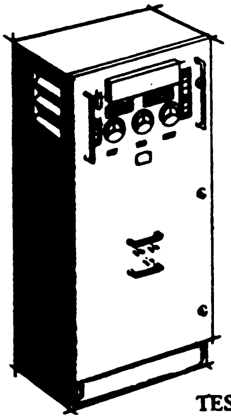
- Accuracy of the designation process
- Accomplishment of the acquisition process
- Adequacy of the fire control system dynamic tracking and the accuracy of the fire control system solution for three-dimensional moving targets
- Dynamic accuracy of launcher response
- Response of the launching system and a simulated missile to the prefiring command.

DSOT Equipment

Accurate weapons system performance depends upon proper functioning of complex, specialized components of the system. Consequently, special test equipment is required to check the system and its components. (See figure 4-8.)



SYSTEM DYNAMIC TESTER
MK 37 MOD 0



TEST SET MK 474 MOD 0

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Figure 4-8.—TARTAR DSOT equipment.

System Dynamic Tester

The System Dynamic Tester (SDT) Mk 37 in conjunction with Test Set Mk 474 performs daily system operability tests on Guided Missile Fire Control System Mk 74 to check designation accuracy, acquisition, track, missile orders, and launcher orders.

Simulation of the fire control system tracking loop can be generated for each of the equipment subsystems in any combination by the SDT. It is possible, therefore, to isolate a cause of trouble to one of the subsystems with a minimum number of test runs. In the digital TARTAR systems the function of the SDT is performed by the missile fire control computer.

Test Set Mk 474

This test set provides simulated moving target rates to test the designation, acquisition, and track accuracy of the fire control radar under dynamic conditions.

Though normally the Mk 474 test set is used in conjunction with the SDT for DSOT, it may also be used independently to conduct a detailed test of the radar parameters.

TERRIER OPERABILITY TEST

The integrated weapons system is capable of operating in several different test modes: Digital Daily System Operability Test (DDSOT); Dynamic Test Panel System Operability Test (DADSOT); RF correlation test; NTDS/WDS end-round test; SPS-48 interface test, overall system alignment test; and on-line system monitoring. In addition, digital shore/surface, casualty, and firing safety readiness tests are provided as part of the overall test program.

The integrated weapons system aboard modernized TERRIER ships features the most comprehensive testing and maintenace program. This testing program is designed to provide more realtistic system testing and rapid fault isolation under both dynamic and static conditions.

The DDSOT mode provides test coverage of the TERRIER weapon system parameters under control of a program stored in the NTDS/WDS Format Control Unit, a general-purpose digital computer which initiates testing, and processes fire control system repeatback quantities. The format control unit provides for dynamic system testing while a major portion of the NTDS remains operational. Rapid fault isolation is facilitated by an NTDS data display group PPI console, which is used to control and monitor all phases of the DDSOT. System performance can thus be evaluated and rapid fault isolation performed under dynamic conditions. Provisions are also made for on-line monitoring of exercise firings.

Accurate missile weapon system performance depends upon the precise functioning of complex, specialized components of the system. Consequently, special test equipment is required to check the system and its components. (See figure 4-9.)

Signal Converter Mk 58

Signal Converter Mk 58, located in the IC, gyro, and missile plotting room, is used primarily during Digital Daily System Operability Tests. The signal converter converts the computer missile order output signals to a format acceptable for entry into the NTDS digital computers.

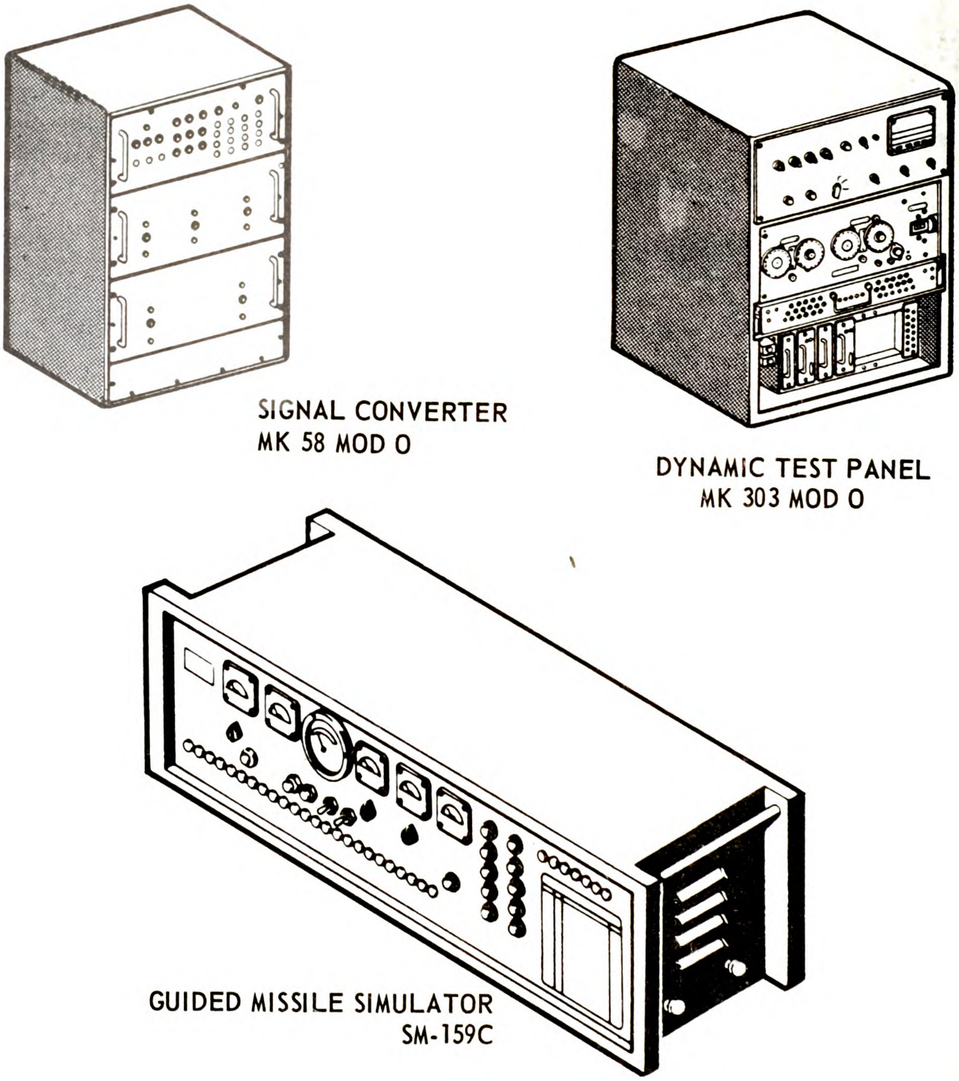

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Figure 4-9.—TERRIER DSOT equipment.

It can also be used during fire control computer troubleshooting and for data collection during exercise firings.

Dynamic Test Panel Mk 303 Mod 0

The dynamic test panel (DTP), located in the IC, gyro, and missile plotting room, provides backup analog test capability for each guided missile fire control system. The DTP also test missile weapon system performance under dynamic conditions. System performance is monitored by dial observation and recording of key functions for subsequent comparison with desired test results.

Guided Missile Simulator

This unit, located either in the TERRIER Training Round (TSAM) or inside the launching system deckhouse, provides electrical load circuits that simulate the loads presented by the various TERRIER missiles during periods of warmup, power changeover, and simulated firing.

Lamps and meters are used to check the transmission of missile orders and operation of the launcher firing circuits.

TALOS OPERABILITY TEST

The purpose of the daily operability test, which is known as the Weapon System Test (WST) on some ship installations and Anti-Aircraft Mode Weapon Parameters (AWP) test on other ship installations, is an assessment of system readiness to engage short-and long-range air tragets, using specified setup and operating procedures. The tests provide interface checks of various system operational and functional modes, submodes, and related system circuits, such as interface checks of search radar-to-weapon direction equipment (NTDS/WDE); fire control radar and guidance transmitter parameters; mechanical and electrical alignment of directors, guidance transmitters, and launchers; and designation and interdirector designation accuracy. These tests are designed to check only key parameters of the weapon system. Many parameters are closely checked to ensure that they lie within specified tolerances, while some, such as the general pulse characteristics of the fire control radars, are given qualitative checks.

As an exmple, the AWP test setup evaluates weapon system operability by simulating an engaged target in a manner similar to an actual engagement. Realistic events are sequenced for observation, appropriate operator response, recording, and evaluation.

Target data processing during the AWP test is effectively the same as that for tactical tracking except for the addition of automatic event sequencing for target and beacon video. This test exercises a simulated TALOS missile flying against a simulated NTDS or WDE designated medium speed, long range target; or a simulated dual missile salvo flying a traverse rate program against a simulated NTDS or WDE designated high speed, close range target. Also, initial missile beacon fading and terminal phase target fading exercises system interfaces and operator proficiency.

SAFETY

Your duties as a Missile Fire Control Technician require constant vigilance in the observance of safety precautions. These safety precautions include those concerning electrical and electronic equipment, work involving the handling of explosive ordnance material, work in the vicinity of equipment capable of starting fires or generating toxic gases, work done on high pressure hydraulic and pneumatic systems, and work done with small power tools.

In this chapter we will look at safety in terms of ordnance and fire control system operation.

General safety precautions and basic first aid treatment relating to electricity, electronics, and hand tools are discussed extensively in chapter 14, Trouble Isolation and General Maintenance.

Because of the many specialized devices you will use, and because of the potential hazards in your work, you should consider the formation of safe and intelligent work habits as being equal in importance to the development of technical knowledge and skills. You should always strive to exhibit the attitudes and practices which are characteristic of ''safety-mindedness''. One of your objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions and in avoiding unsafe actions. As a Petty Officer you are obligated, and expected, to pass on to your junior men the safety knowledge and experience you have acquired through your own training and to demonstrate good safety habits.

Each Missile Fire Control Technician is expected to observe all of the safety precautions set forth in local directives, in equipment maintenance manuals, and in Naval Ordnance Systems Command Ordnance Publications (OPs) and Ordnance Data (ODs).

SAFETY PHILOSOPHY

In a study of safety precautions, it is difficult to cover every possible situation that may arise and which, if improperly handled, may produce serious results. However, if a thorough understanding of the basic ideas behind the precautions is developed, unsafe conditions can be recognized and corrected and, further, suitable action can be taken instinctively when the unexpected occurs.

The actions and attitudes which are to be carefully avoided are carelessness, noncompliance with procedures, lack of alertness, disorganized hast, ignorance, and over confidence in the performance of your duties.

In addition to system manuals and publications which contain safety precautions applicable to a specific system, a partial list of ordnance publications concerning safety of interest to FTMs would include the effective edition of:

United States Navy Ordnance Safety Precautions (NAVORD OP 3347)
Ordnance Safety Precautions, Their Origin and necessity (NAVWEPS OP 1014)
Ammunition Afloat (NAVORD OP 4)
Ammunition ashore (NAVORD OP 5)
Radio Frequency Hazards Manual (NAVORD OP 3565/NAVAIR 16-1-529)

GENERAL SAFETY PRECAUTIONS

Even though the guided missile and the missile fire control equipment is complex in operation and uses propellants and explosives, the handling and testing are relatively safe when the proper equipment and procedures are used.

All operations should be performed carefully, methodically, and without hurrying. Greater effectiveness in the assembly and launching of the missile will be developed by increased familiarity of your assigned duties. During any missile handling operation, if a malfunction occurs or an incorrect indication appears, STOP the operation immediately and determine whether or not it is safe to proceed. Before performing any step in a procedure be sure that the preceding step has been properly executed and the correct results obtained.

Cleanliness and good housekeeping in all working areas are major factors in effective accident prevention. Tools and equipment should be maintained in good working order and should always be returned to their proper storage places after usage.

Safety devices found on mechanical or electrical systems are put there for your protection and the protection of the equipment. These devices must be maintained in good order and operative at all times. You should never remove safety devices or bypass them unless specifically authorized. Where safety devices have been rendered inoperable by proper and specific authorization, adequate notices shall be posted to warn personnel of the potential hazard.

Avoid the use of flammable or toxic cleaning fluids such as gasoline, benzine, ether, and alcohol. The use of carbon tetrachloride is prohibited.

Precautions With High Pressure Fluid Systems

As you know, missile control systems contain power sources which involve the use of accumulators charged from gas bottles, or cylinders, containing compressed air or nitr gen. The high pressures involved make it nec sary that extreme caution be exercised by p sonnel in charging the accumulators and g bottles, and in handling the containers in whi the gases are stored. The following are som basic precautions regarding pressurized g containers.

1. When charging gas bottles, be sure t all personnel not required for the work a cleared from the area. Also ensure that prop protective equipment (including goggles) is wor by all persons during charging.

2. Never drop gas cylinders or permit the to strike each other.

3. When returning empty cylinders, be su that all valves are closed, that valve protect caps are in place, and that the proper residu pressure is maintained.

4. Do not tamper with any safety device o valve in the container or the associated equip ment.

5. Do not refill any container with gas unles such action has been specifically approved, an then only in accordance with explicit instructions EXPLOSIVE MIXTURES MAY BE FORMED I CYLINDERS CONTAINING TRACES OF COM BUSTIBLE GASES WHEN THESE ARE RE FILLED WITH COMPRESSED AIR.

6. Do not use regulators, pressure gages manifolds, and related equipment designed for particular gas on cylinders containing a differen gas.

7. Never discharge a cylinder into any devic or equipment wherein the gas will be entrappe and build up pressure, unless the cylinder i equipped with a pressure regulator or simila safety device.

8. Use soapy water when testing for leak in a gas container.

9. When it becomes necessary to drain cyl inders containing toxic or irritant gases, b sure that there is no possible hazard to personne or property. For these operations, ensure tha personnel are provided with protective clothing goggles, and breathing masks.

Accumulator Handling and Charging

Accumulator units in hydraulic systems mus be charged with dry air (or nitrogen) and hy draulic fluid in strict accordance with the pro cedures given in the missile technica publications. Never charge an accumulator wit oxygen since that gas is highly explosive. Al hydraulic fluid and air charges must be discharged from accumulator units before hydraulic sections are removed from a missile.

Before applying test pressures to the missile, be sure that all air and hydraulic connections are well secured. Loose connections are, of course, dangerous since escaping gases could cause serious injury and damage. Make sure that all missile ground wires are in place before starting a test, and, by all means, keep your hands away from wings and fins when the control section of the missile is energized to avoid injury from moving surfaces.

Before hydraulic units are put into operation, be sure that all personnel not needed in the process are cleared from the area. Upon completion of systems tests be sure that the air and hydraulic supplies have been turned off and bled BEFORE removing the lines from the missile. Keep the hands and other parts of the body well clear of exhaust streams when working with test equipment employing high pneumatic pressures.

ORDNANCE PRECAUTIONS

Missile ordnance materials include rocket motors, igniters, fuzes, warheads, boosters, etc. All of these units are potentially dangerous. They must be handled in accordance with the specific procedures authorized in the appropriate publications. The following precautions are to be observed in addition to the detailed directions given in the missile technical manuals.

1. All safety devices provided in ordnance units must be used exactly as designated. Every effort should be made to keep these in proper operating condition at all times.
2. Changes, modifications, or additions to ordnance items may be made only upon explicit direction from the Naval Ordnance Systems Command.
3. No explosive assembly is to be used in any way except that which is designated by the proper authority.
4. Electric igniters, VT fuzes, detonators, and electrically fired rocket motors must be carefully protected from radiofrequency emission. None of these units should be exposed within 5 feet of any operating electronic transmitting equipment, including antennas and antenna leads. When the transmitting apparatus is a part of authorized test equipment or is a part of the weapons system, special instructions concerning its operation must be followed. No danger exists, however, from radiofrequency potentials with detonators of any type while they (the detonators) are completely enclosed in metal containers.

5. Warheads and fuzes must be protected from abnormally high temperatures. If exposed, they must be handled in accordance with current instructions of the bureau concerned.

6. Normally, warheads are issued unfuzed. Fuzes shall not be inserted until just prior to flight time. Fuzing shall not be accomplished near a magazine, but may be accomplished in handling rooms or spaces specially designated by competent authority. When fuzing takes place missiles should be isolated from other ammunition as far as is practicable.

7. Be sure that the missile airframe is well grounded electrically at all times. Before connecting igniters in rocket motors, check the firing leads for stray or induced voltages and for static charges.

8. Before handling any piece of ordnance material, inspect the safety device to be sure that it is in the SAFE position. If not, the unit must be made safe by experienced personnel before further work is carried out.

9. Before installation in rocket motors, the igniter should be inspected to see that the case and safety switch are free from damage. If damage is found, the entire assembly should be rejected.

10. Safety pins in fuzes, or any other device requiring removal or adjustment before flight, must be removed or adjusted only after the missile has been placed on the launcher.

11. Missiles not expended on live runs must be made safe at the first opportunity in accordance with current instructions for the various ordnance assemblies.

12. No motor assembly that has been dropped should be fired.

13. Disposal of rejected motor assemblies must be made in exact accordance with local regulations governing the particular type of unit.

14. Never use power tools for any work on the motor, nor apply heat to it or to any associated component.

15. Some rocket motors can be ignited by static charges carried by personnel or built up on ungrounded equipment. Be sure that the motor case is grounded during all handling operations.

16. In case of rocket motor misfire, personnel must not approach the rocket for at least 30 minutes, or until the firing circuits are known to be open.

17. If it is learned during handling that any motor or booster is in the armed condition, the unit must be disarmed before proceeding with further activity.

Missile Component Stowage

A storeroom for stowage of missile components and a magazine for the stowage of missile warheads are normally located below decks and below the checkout area. The magazine and the storeroom may be connected to the checkout area by a trunk and/or hoist.

The location of the stowage spaces varies with the type of ship and the missiles carried. If you have missiles (Terrier and Talos) that have wings and fins to be installed when preparing for firing, the wings, and fins are stowed in racks in the loading area of the launching system. Tartar missiles have their wings attached and folded, so there is no need for separate stowage, except for spare parts. A dumbwaiter type of elevator operated by an electric hoist is used to move the spare parts to or from the missile component storeroom.

Stowage Precautions

Classes of dangers can be grouped as general, personnel, mechanical, electrical, and explosive. To these we might add danger from liquid fuels, and danger from radioactive material. The following are a few specific precautions to review.

A. Missiles and components must be securely fastened in storage, stowage racks, and magazine ready service rings.

B. ALWAYS inspect handling equipment before using.

C. Missiles and components must NOT be placed in or removed from stowage racks and/or areas without using the proper handling equipment.

D. All arming devices must be in the SAFE position during stowage.

E. Arming tools must be kept in a designated place at all times, except when in actual use.

F. Ground wires must be attached to boosters and missiles in stowage, during check-out, and while being transported from one area to another.

G. Booster rocket components must be handled with care. A cracked propellant grain could result in an explosion when ignited.

H. Explosive and propellant components must be stowed in approved magazines in which the temperature range does not exceed the limits specified by NAVORDSYSCOM.

General Stowage Precautions

A. All missile operations must be in accordance with shipboard safety precautions.

B. Handling of sustainers, booster's warheads, and other propelling or explosive devices must conform with explosive handling practices aboard ship.

C. Only those personnel who are engaged in the operation in progress should be permitted in the immediate area of the missile.

D. Only approved nonsparking tools are to be used in the vicinity of explosives or propellant charges.

E. Only the correct handling equipment is to be used for lifting missiles and their components.

F. Electrical equipment must be shielded and grounded to prevent accidental ignition of propellants or explosives or injury to personnel.

G. Working areas must be clear of obstructions, loose cabling, hose, and unneeded equipment.

H. Electrical ignitors or detonators (booster charges) shall not be exposed within 50 feet of, or stowed in any compartment with, any exposed electronic transmitting equipment, exposed antenna, or antenna lead, except where such apparatus or antenna is part of a missile test set, or is an integral part of the missile concerned.

I. Use extreme care in handling pressurized air hoses and couplings. Compressed air can exert sufficient force to severely injure personnel and/or equipment.

FUELING PRECAUTIONS

There are certain safety precautions which you must observe when fueling a missile. Among these are the following:

A. Before fueling the missile, check the fuel system for damage of any kind.

B. Keep the number of personnel to a minimum during fueling or defueling.

C. No smoking in the fueling areas.

D. Always know the tank pressure and the osition of the fuel shutoff valve.

E. Never actuate the shutoff valve when the ank is charged.

F. Check for any signs of fuel leaks during towage.

G. Observe all safety precautions applicable o combustible materials.

NEUMATIC AND HYDRAULIC SAFETY

Hydraulic systems operate under hydraulic ressures ranging from approximately 100 psi to ,000 psi. Some pneumatic systems operate in pproximately the same range of pressures as ydraulics. These pressures are dangerous and an be hazardous to personnel.

The following safety rules are but a few of he many that must be observed when operating r working on hydraulic or pneumatic systems.

A. Never disconnect hydraulic lines or disassemble hydraulic equipment when the hydraulic system power motor is running.

B. Never disconnect hydraulic lines or disassemble hydraulic equipment until the accumulators have been manually dumped.

C. Never manually actuate switches, solenoids, relays, or valves on hydraulic systems under pressure unless you are qualified to perform these actions.

D. Report hydraulic leaks immediately so that they may be repaired at the first opportunity.

E. If clothing becomes drenched with hydraulic fluid, immediately change into dry clothing for hydraulic fluid is injurious to health when in prolonged contact with skin. It is also a fire hazard. Immediately wipe up all spilled fluid.

F. Do not direct a high-pressure air jet at any part of the human body; this may be fatal.

Safety precautions must be observed when performing maintenance, testing, and operating ordnance hydraulic and pneumatic equipment. The high pressure liquid or air can cause major injuries to your face, hands, and other parts of the body by jets of air or liquid escaping from valves or pipe connections which are highly pressurized.

Don't think that once you have learned all applicable safety precautions you can sit back and take things easy. Review them periodically, particularly those for jobs seldom performed. Try to improve upon any rules in effect. Safety is everyone's responsibility, not just those who drew up the regulations. Most accidents are caused by men who are so familiar with their job they think they can take short cuts; by men who don't know the applicable precautions; by practical jokers; or, in the majority of instances, by plain carelessness.

HERO PRECAUTIONS

The hazards of electromagnetic radiation to ordnance (HERO) problem has become acute. The number and variety of electrically initiated explosive devices are increasing rapidly. For example, some currently operational weapons contain more than 75 electroexplosive devices. Continuing development efforts are directed toward reducing weight and space requirements, lowering power requirements, assuring positive response, and increasing safety and reliability. However, these goals are not always complementary.

At the same time, the power of communications and radar transmitting equipment is constantly being increased and the frequency spectrum broadened. The radiofrequency spectrum now used in the fleet extends from 10 kHz to about 20,000 MHz. Transmitter power outputs extend to 10 kw at communications frequencies, and peakpower outputs extend to approximately 5 megawatts at radar frequencies.

These trends produce situations which are in direct conflict with each other. On the one hand, transmitters and their antennas have only one purpose—to radiate electromagnetic energy. The initiating elements of ordnance devices need only to be supplied with the proper amount of electrical energy for an explosion to take place. Therefore, with many explosive ordnance items, certain precautions are required for safety and to insure reliable performance.

To meet the growing need for new procedures to reduce the hazards to ordnance equipment from RF radiation, the Naval Ordnance Systems Command (NAVORDSYCOM) has sponsored tests which, coordinated with studies made by other agencies, have provided new guidelines and restrictions for handling electrically initiated ordnance equipment.

The basic problem in determining an ordnance system's susceptibility to RF radiation lies in the evaluation of the antenna like couplings that exist between radiating fields and the electroexplosive devices in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin, or it may be conducted into the weapon by the firing leads or other wires leading into the weapon.

The exact chances of electroexplosive device firing are quite unpredictable, being dependent upon such variables as frequency, field strength, positional and directional orientation, environment, and metallic contact with the weapon.

The most susceptible period is during assembly, disassembly, loading, unloading, or testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of the reliability of the device, or propellant ignition. In extreme cases, there is a definite possibility of warhead detonation.

Some specific safety precautions which the technician must observe with respect to these weapons and ordnance devices include the following:

1. Turn off all RF transmitters during weapon handling operation in the area.
2. Observe all local and general safety and HERO restrictions.
3. Maintain radar silence during assembly, disassembly, loading, unloading, or testing operations.
4. Avoid exposure of ordnance devices to high power RF transmitters.

FIRE CONTROL SYSTEM OPERATION

Before you operate fire control equipment aboard ship, let up repeat that you should acquaint yourself thoroughly with the safety precautions provided in your system and equipment OPs. You must, also, become familiar with shipboa safety regulations. You will be taught how apply many of these precautions while you a learning to operate fire control instrumen The following list of general precautions w assist you.

1. Always inspect all training and elevati areas to make certain that all persons are clea and that the areas are free of obstructio before operating directors or missile launcher
2. Always use warning bells before traini or elevating launchers during routine work a practices.
3. Before securing directors and launche always train and elevate them to their s positions; place all controls in the inoperat position, and deenergize all power suppli
4. Slew directors and launchers only wh it is necessary during practices.
5. All telephone stations should be mann when operating systems automatically or r motely.
6. Notify all operators and persons concern before shifting a system to automatic.
7. Never operate directors or launchers automatic without having the regular operato posted at their stations.
8. Do not hesitate to stop any person fr operating fire control equipment if he may cau a casualty to himself, the equipment, or to a other person.

CHAPTER 5

BASIC COMPONENT PARTS

INTRODUCTION

As a Missile Fire Control Technician, you are oing to be involved with equipment that is aborate and complicated. All of this equipment ntains components, basic in nature, that can be assified as mechanical, electromechanical, or ectrical. This chapter is a presentation of basic omponent parts.

It is not intended, however, to highlight specific omponent parts of equipment that you may be oncerned with as a Terrier, Tartar, Talos or asic Point Defense FTM. Instead, the comments re directed toward components that are basic o all missile fire control systems.

After completing this chapter, you will have ained a knowledge of components that is essential r the operation of equipment that you are ssociated with as a missile Fire Control Techcian. You will be able to apply this knowledge oward analyzing the component parts of your hip's particular fire control equipment.

This chapter is divided into three sections. The irst section is directed toward mechanical comonents, the second toward electromechanical, and he last toward electrical components. The aterial presented here is dependent upon Basic achines, NavPers 10624-A and Basic Elecricity, NavPers 10086-B for principles applicable o basic components.

MECHANICAL COMPONENTS

HAFTS

Shafts provide a mechanical means of transnitting motion between units. There are two asic types of motion: angular (rotary), and inear (translatory). Shafts can transmit either ype of motion. A moving shaft can transfer nergy from one point to another. For example, n a motor-generator set the motor is coupled o the generator by a shaft. The torque produced in the motor is transmitted to the generator to rotate it at a definite speed. Of prime importance in this application is the number of shaft revolutions per unit of time. In this application the angular position of the shaft has no practical value. A shaft, however, can also transmit angular data.

Among the first things you see when you look inside most of today's missile analog fire control computers are mechanical modules which help to solve the missile fire control problem. These modules contain many shafts and gears. They are there for a specific purpose: to connect computing units and to position dials.

The angular positions of the shafts that couple these computing devices represent actual quantities—degrees of an angle or yards or range. The amount of change in the transmitted quantity represented by one revolution of a shaft is called shaft value. The total value carried by a shaft is the shaft value multiplied by the number of revolutions made by the shaft from its zero or reference point. For example, the shaft value for bearing data in an instrument might be 10° per revolution. If the shaft made six and a half revolutions from its zero position, bearing in the instrument would be 65°. Shaft value is a design feature and can be made to represent any reasonable value. Generally speaking, however, accuracy decreases with an increase in shaft value. Shaft value is the ratio between shaft motion and the change in value of the quantity being transmitted. Later in this course we will discuss scale factor in a computer. The two terms have similar meanings.

The accuracy with which a shaft can be positioned depends in part on the resistance to shaft motion. In many installations the power available is limited. This is particularly true in analog fire control computers where space and weight are critical commodities. Moreover, in servosystems the power output is directly related to the error size. Thus as the shaft approaches the correct position the power is reduced.

Friction between moving parts must be held to a minimum. Shafts are mounted in ball bearings housed in carefully machined parts to reduce friction and to ensure as near perfect rotational alignment as possible. Misalignment between the rotational axes of a shaft line and its associated components will cause eccentric rotation which, among other things, will increase the resistance to motion.

COUPLING DEVICES

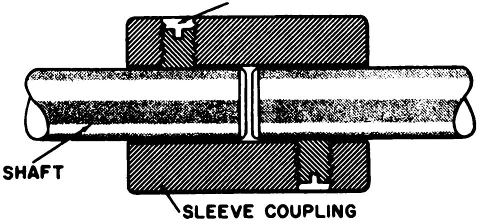
Coupling devices are used to mechanically connect shafts together to form a shaft line or gear train. Coupling devices are covered in Basic Machines, NavPers 10624-A. Therefore, our discussion here will be limited to their application in fire control equipment. As a connecting link between shafts, they provide a means to compensate for the misalignment between the axes of rotation of the shafts, and for end play in the shaft line. They also make it possible to adjust the rotational angle between the shafts. Coupling used in fire control equipment to connect shafts end-to-end are: the sleeve, the Oldham, the flexible, the universal joint, and the quick disconnect.

Sleeve Coupling

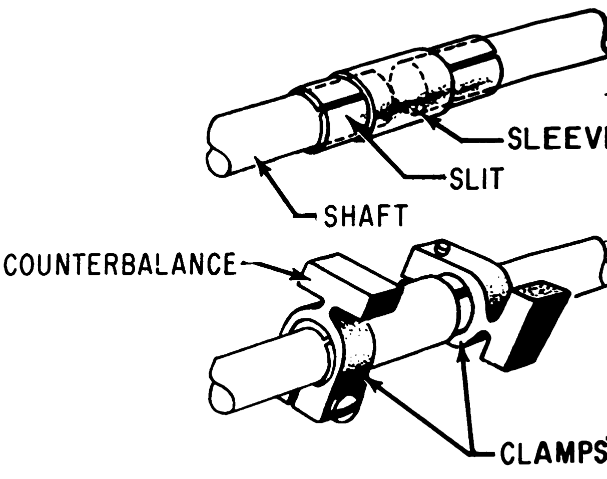
Figure 5-1 shows a plain sleeve coupling which consists of a simple metal tube or sleeve that receives the ends of two shafts it is to join, and is secured by set screws or pins so the assembly can turn as one. It is used to join two shafts that lie in the same straight line; that is, shafts that are very closely aligned with little need for disconnecting.

Figure 5-2 illustrates a clamp type sleeve coupling, the sleeve of which is slit at each end. The slit ends enable the clamps to fasten the sleeve securely to the shaft ends. When t clamps are tight, the shafts are held firm together and turn as one shaft. They serve a convenient device for making adjustments between units.

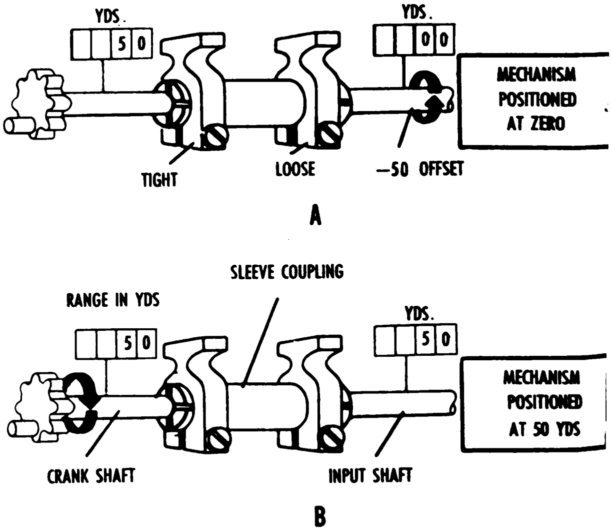
Figure 5-3 depicts a mechanism which receives range, via a shaft, from a handcrank.



167.731
Figure 5-1.—Plain sleeve coupling.



12.5
Figure 5-2.—Clamp type sleeve coupling.



110.1
Figure 5-3.—A coupling used to adjust a sh line.

part A of the figure, the range indicated in the mechanism does not correspond with that introduced by the handcrank; there is a 50 yard offset. This condition can be corrected by loosening he sleeve coupling, rotating the mechanism shaft ntil the two range values agree, as in part B of the figure, and then retightening the coupling.

Flange Coupling

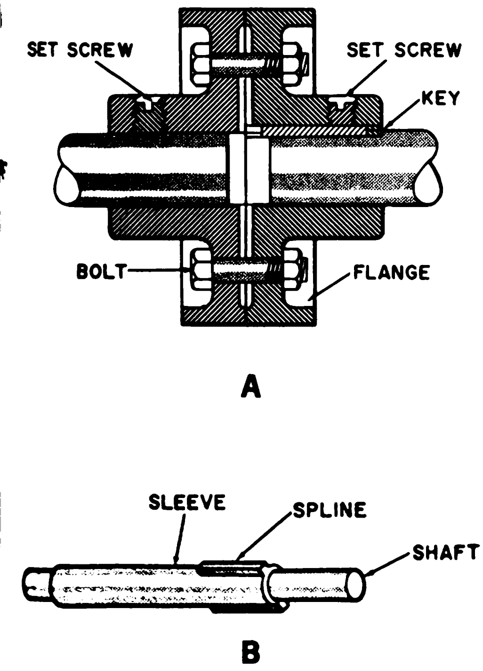
The flange coupling finds use on shafts which end to be pulled apart in operation, figure 5-4. A pair of flanges, secured to the ends of the shafts by set screws, are pulled together by bolts and nuts. Splines or keys are resorted o in the case of heavy duty drives.

Oldham Coupling

The important feature of the Oldham coupling, named for its inventor, is that it can be readily connected. It is used to join shafts that do not require perfect alignment. You can see this coupling in figure 5-5.

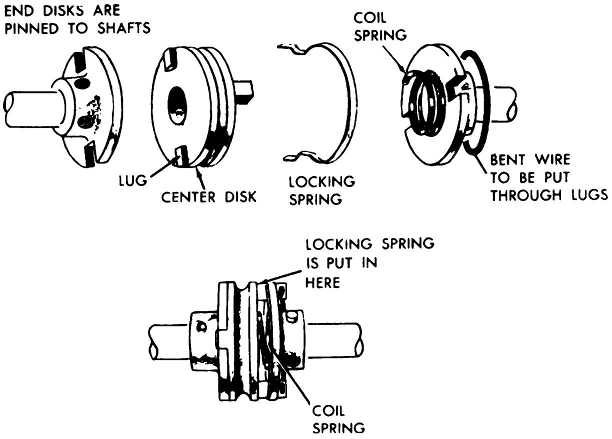
The Oldham coupling has another use. As ou know, metals expand and contract with changes in temperature. Because of its spring loading it also finds use as an expansion joint in long shafts. The Oldham coupling consists of a pair of disks, one flat and the other hollow, pinned to the ends of the shafts. A third disk, with a pair of lugs projecting from each face, fits between the shaft disks. The lugs fit into slots of the two end disks, and enable one shaft to drive through the disks to the other shaft.

A helical or coil spring, housed within the center and hollow end disks, forces the center disk against the flat disk. With the coupling assembled on the shaft ends, a flat lock spring is slipped into the space about the coil spring. The ends of this flat spring are formed so that when it is pushed into place the ends spring out and lock about the lugs. A bent lock wire is passed between holes drilled through the projecting lugs to guard the assembly. It is a simple matter to remove the bent lock wire, withdraw the lock spring, compress the coil spring by pushing and sliding back the center disk, and disconnecting the shafts. Reinstallation requires no measuring or setting as the assembly fits quickly and smoothly into place.



167.732

Figure 5-4.—A. Flange coupling; B. Spline on shaft.

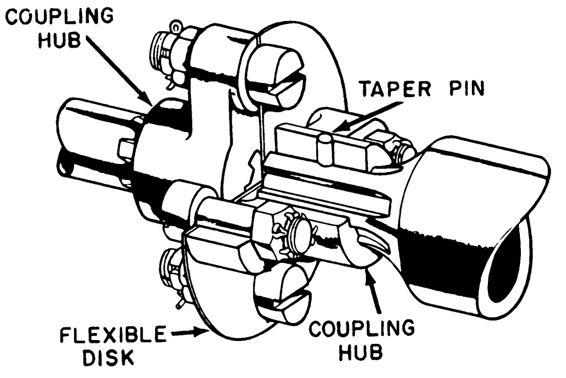

END DISKS ARE PINNED TO SHAFTS
COIL SPRING
LUG
CENTER DISK
LOCKING SPRING
BENT WIRE TO BE PUT THROUGH LUGS
LOCKING SPRING IS PUT IN HERE
COIL SPRING

12.52

Figure 5-5.—Oldham coupling.

Flexible Coupling

The flexible coupling shown in figure 5-6 connects two shafts by means of a metal disk. The coupling hubs are splined to the two shafts and are bolted to the metal disk. The flexible coupling can compensate for a slight misalignment of the shafts.



84.133.2

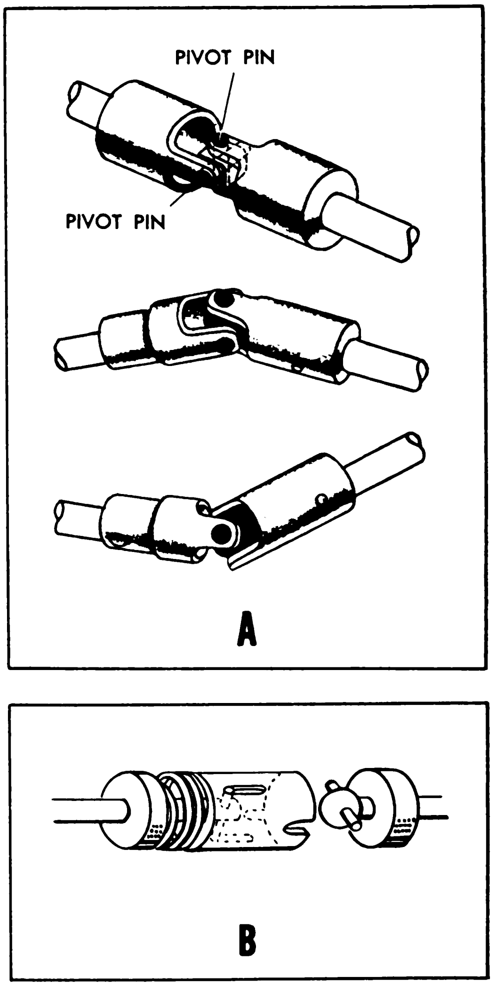
Figure 5-6.—Flexible coupling.

Universal Joint

A shaft line or gear train is usually put together in such a way as to turn corners to get around units, and so on. This requires the rotational axes of connecting shafts to intersect at an angle, rather than in a straight line. The universal joint (fig. 5-7A) is used to connect shafts that intersect at angles up to 25°.

Quick Disconnect Coupling

The quick-disconnect coupling (fig. 5-7B) is used where it is often necessary to remove a subassembly. The male or pinned shaft fits into the open slots of the sleeve. The sleeve is kept from slipping by a pin through the shaft and the closed slot in the sleeve. A spring holds the sleeve in place. To disconnect the shafts, the sleeve is merely pushed back against the spring pressure.



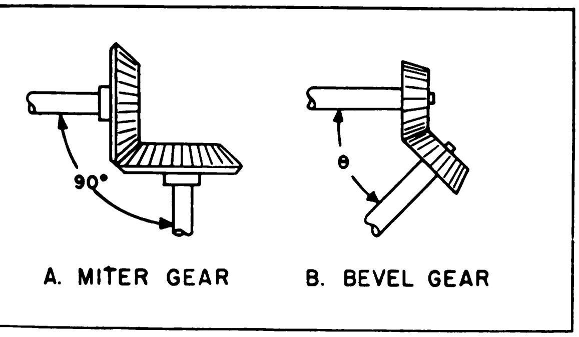
5.34

Figure 5-7.—A. Universal joint; B. Quick-disconnect.

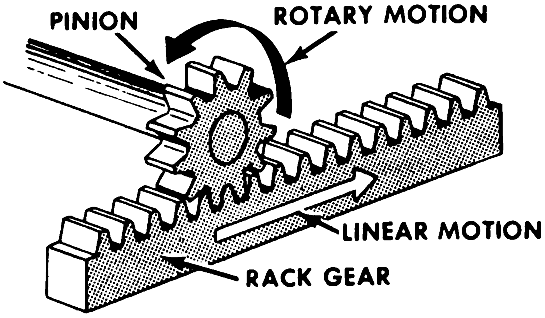
Gears

The devices most often used to couple shafts together are gears. Gears may also be used to change the angle of a shaft line's rotation (fig. 5-8); to reverse the shaft line's rotary motion (fig. 5-9); to increase or decrease the speed of rotation and thus change the amount of rotation and the mechanical advantage of the shaft line (fig. 5-9); and, finally, to convert one type of motion, (linear, angular, etc.) to another (fig. 5-10). As you can see, a gear is a very versatile basic mechanism. Gears are covered in Basic Machines, NavPers 10624-A. Be sure your understand the applications of each type of gear and the principles of gear ratio. You will need thi information in your study of many kinds of fir control equipment.

LOST MOTION.—The tolerance for error in fire control equipment is very small. Sinc many of the shaft lines carry angular dat which must be accurate to the nearest minut of arc, it is important that the gears fit accuratel and with a minimum of lost motion. A mechanical device, in order to move, must have roor to move. Consequently, a small amount of spac is necessary between mating mechanical components, such as gears, to allow them to move. Thi space results in lost motion. Lost motion i



5.22.24
gure 5-8.—Angular change of shaft line axis.



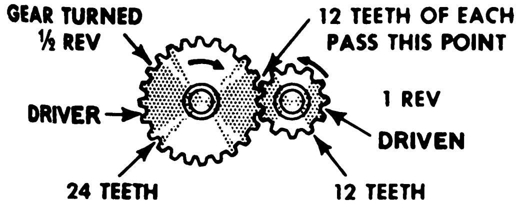
5.22.13
Figure 5-10.—Angular to linear motion.

e distance the driver gear turns before the
iven gear begins to turn. This distance is
lled dead space. The total lost motion in a
ear train is the sum of the lost motion in each
ear mesh. Lost motion adds up to a consider-
ble error on a long shaft line with many gear
eshes, figure 5-11.

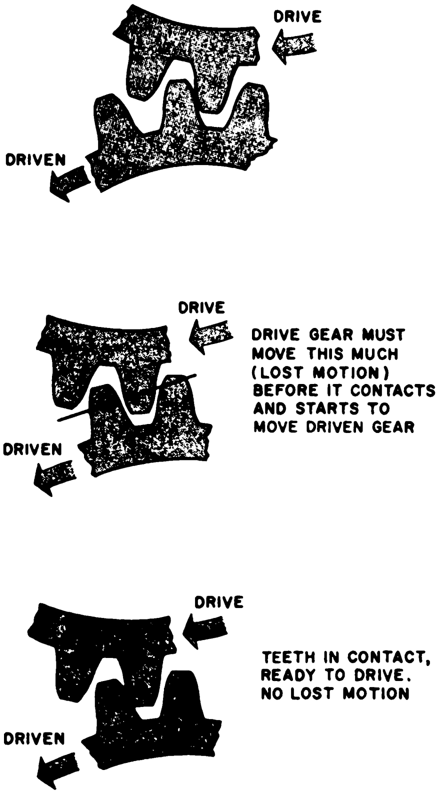
CLASSES OF GEAR FITS.—The dead space
bviously reduces the accuracy of data trans-
itted by a gear train. In power transmission
ystems, the dead space will cause backlash in
e drive. Backlash results in a jarring or jerky
eaction to sudden movements, or to a reversal
f the motion. This is a particularly serious prob-
m where the load has a large amount of inertia
ue to its weight or velocity.

The degree of accuracy required of a gear
ain varies for different applications. In com-
uters, the gears are meshed or fitted very
losely to reduce lost motion. In other appli-
ations a specified clearance between the driver
d driven gears' tooth surface is allowed.
e will list a representative group of classes
gear fits used in the assembly of a fire
control instrument. The clearances for the different classes represent a compromise between accuracy and other operational characteristics.

A CLOSE FIT has a very high percentage of the driver and driven gear's tooth surface in actual contact. This fit is used in computing instruments because it has a minimum of lost



167.733
Figure 5-9.—Gear ratio.



167.734
Figure 5-11.—Lost motion.

motion. Gears so fitted should turn smoothly, but may require an additional torque due to the friction caused by the large area of contact. The mesh between gears in this class of fit is critical. If the gears are meshed too closely, the line will jam. A loose mesh, on the other hand, will introduce lost motion.

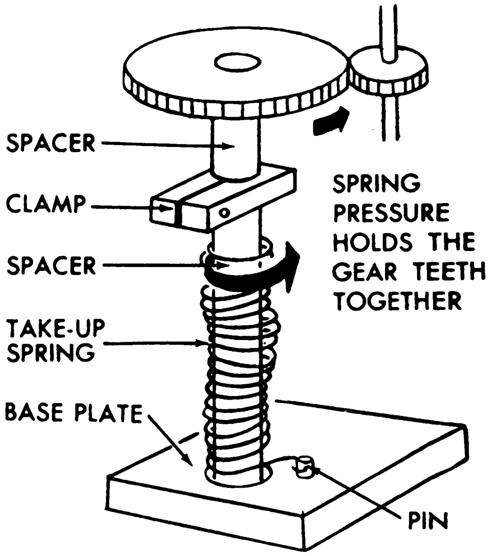
A RUNNING FIT has some dead space. There is a clearance between adjacent surfaces of approximately .001" to .002". In a gear mesh, the stated clearance is equal to half the lost motion which may be accumulated by loading the gear.

A CLOSE RUNNING FIT is midway between a close fit and running fit. This is the normal fit used in the assembly of fire control instruments unless another class is specified.

A FREE FIT has a clearance of approximately .003" to .005" between mating tooth surfaces. This fit is not critical, and can be determined by "feel."

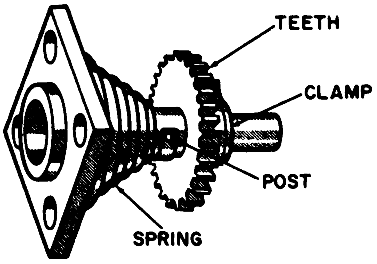
A FREE RUNNING FIT is midway between a running fit and a free fit. It has approximately .002" to .003" clearance between surfaces.

LOST MOTION TAKEUP SPRING.—Once a shaft line is turned, all the dead space between the gears is removed in the direction of rotation. With the dead space gone, there is no more lost motion in this direction. A lost motion takeup spring removes the dead space by holding the driving gear teeth firmly against one side of the driven gear teeth. The usual form of takeup spring (fig. 5-12) has one of its ends attached to a mounting plate or to the machine housing or base plate. The other end is attached to a clamp fixed on the shaft. The clamp is generally set in place between spacers, the latter pinned in place. The spacers prevent the clamp from being pulled along the shaft when the spring tension is being adjusted. Spring pressure applies a torque to the driving gear both while the shafts are turning and while they are stationary. Spring adjustment can be made by loosening the clamp to wind or unwind the spring, depending upon whether an increase or decrease in spring tension is desired. The takeup spring shown in figure 5-12 is used with shaft lines that have a limited amount of rotation. Other takeup springs may be mounted for use with shaft lines with unlimited rotation.



12.26

Figure 5-12.—Lost motion takeup spring.



167.73

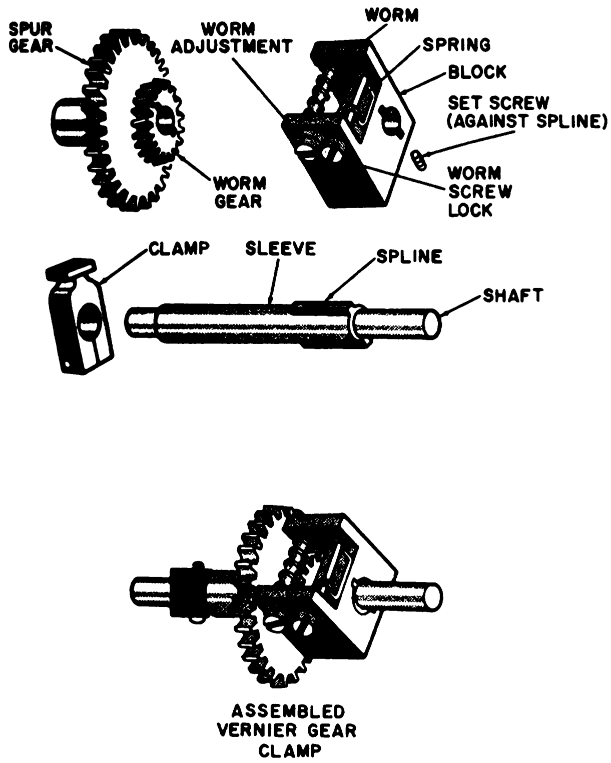
Figure 5-13.—Takeup unit.

TAKEUP UNIT.—A takeup unit that uses a flat or clock type of spring is used when a short shaft prohibits employment of the spiral takeup spring, figure 5-13. In this unit one end of the spring is secured to the housing. The othe end of the spring, pierced with a hole, is slippe over a pin on the cap of the unit. Spring adjustment can be accomplished by loosening th clamp and turning the cap to the desired position reclamping to retain the particular tension

VERNIER GEAR CLAMP.—A vernier gea clamp is used to provide a fine adjustment fo positioning a gear on a shaft. The vernier permits the gear to be turned very small amount relative to its shaft.

The components of the vernier gear clam are depicted individually in figure 5-14. Assembl is accomplished by slipping the sleeve, with integral splines, on the shaft. The spur and worm wheel component fits on, and can turn on, the sleeve. The block is formed to fit the sleeve and its splines. One set screw (or more), bearing on the spline, holds the block securely on the sleeve. A clamp is used to secure the sleeve to the shaft.

We can secure an approximate or rough setting of the spur gear by loosening the clamp and revolving the assembly on the shaft to the initial position. The clamp is then tightened. Manipulation of the worm adjustment will very accurately position the spur gear relative to the shaft. The worm adjustment screw has a flange and, when proper setting is secured, is held in this position by the head of another screw called the worm screw lock. End-shake of the worm is eliminated by a bent washer spring under a collar on the end of the worm. This serves to hold the worm and worm gear in close mesh to eliminate lost motion and hold the accurate adjustment.



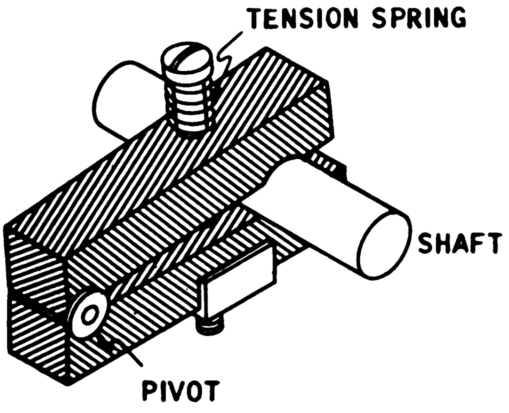
167.736

Figure 5-14.—Vernier gear clamp.

HOLDING FRICTIONS

Gear trains employ holding frictions (fig. 5-15) to keep a desired shaft value, which has been manually set in, from moving during normal operation.

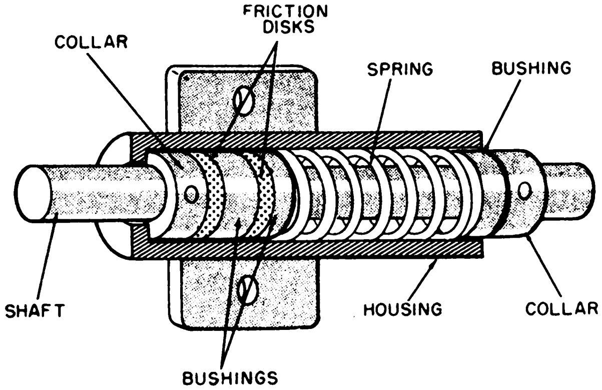
A typical example is composed of two blocks of bakelite which are pivoted at one end and notched at the other, and provided with an adjusting screw. Adjustment of these holding frictions is straight-forward; adjust the screw until the pressure exerted on the shaft is sufficient to hold the dials at any desired value, yet loose enough to permit the gear train to be moved without undue force.



167.46

Figure 5-15.—Holding friction.

Another shaft friction holding device used to prevent oscillations and shaft values from backing up (fig. 5-16) is comprised of a housing, bolted to some part of the equipment so it is held stationary, through which the shafting is run. By means of a spring exerting pressure on friction disks which "brake" against the bore of the housing, a degree of friction is set up which must be overcome before the shaft can turn. The holding friction developed by the friction disks depends upon the force applied to them by a helical spring. Spring pressure can be adjusted by moving the collar to a new position.



167.737
Figure 5-16.—Spring pressure holding friction.

CAMS

A cam is a specially shaped surface, projection, or groove whose movement with respect to a part in contact with it (cam follower) drives the cam follower in another movement in response, figure 5-17.

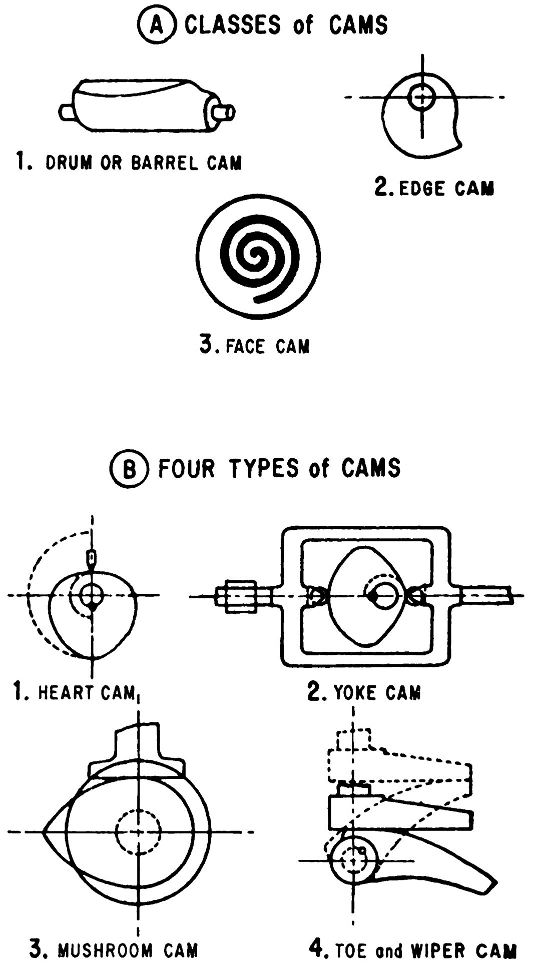
Microswitch Cam

One extensive fire control application of cams is in the operation of microswitches (fig. 5-18). (Microswitches are small, short travel, snap-action, electrical switches.)

Cams that are used to activate microswitches are coupling devices in the sense that they transfer mechanical knowledge to an electrical circuit. Physically, these cams are composed of two flat disks, each of which has a portion of its circumference cut away.

When used in conjunction with a microswitch, the cam follower will depress the switch when the follower is riding on the activating surface. The switch will not be depressed when the follower is riding in the cutout portion. Two disks are provided so that, by rotating each disk with respect to the other, the arc length between the risers can be varied, thus determining the length of time the switch remains activated and deactivated.

Adjustment of microswitch activating cams should be made in accordance with approved adjustment procedures, normally set forth in equipment Ordnance Publications. In general, the adjustment procedure will consist of the following sequential steps:

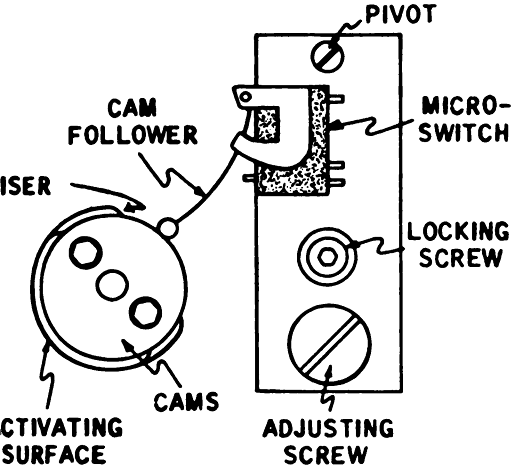


5.29
Figure 5-17.—Classes and types of cams.

1. Adjust the switch location until pushbutton activation is centered midway up the riser portion of the cam (fig. 5-18), without bottoming the pushbutton at the top of the riser. This is accomplished by loosening the locking screw and rotating the eccentric adjusting screw, both of which are located on the microswitch mounting block.

2. If the adjustment procedure calls for a definite activation spread, loosen the two hexagonal screws that hold the cam discs together, and rotate the discs until the desired spread is obtained.

3. Loosen the specified adjustment clamp and rotate the cam until the switch activates and deactivates at the dial readings indicated in the adjustment procedure.



167.47
Figure 5-18.—Cam and microswitch.

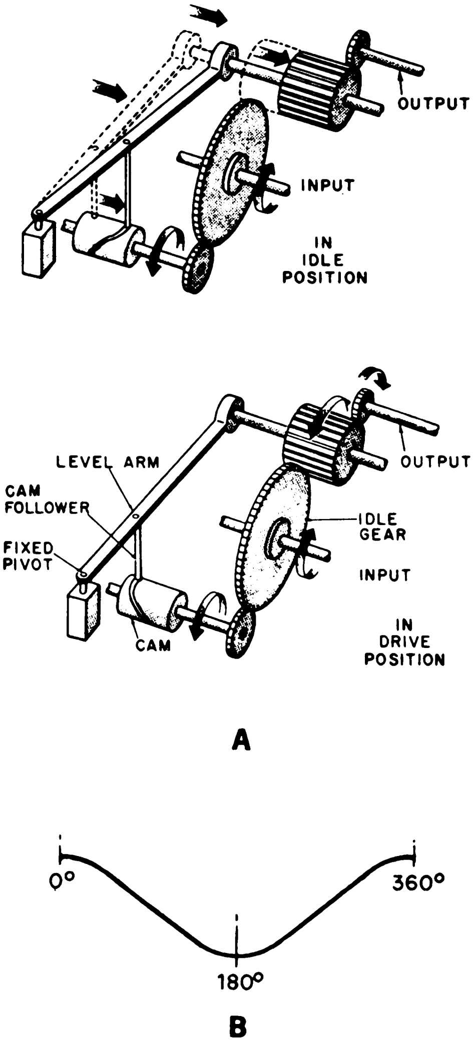
Cam and Lever Shift

A mechanism supplying a force which slides ever arm in and out of position at certain its is required to provide automatic engage- t and disengagement. As the motion of a t is rotational, a device is required for conversion of rotational motion to linear ion. An assemby comprising a grooved cam, follower, lever, and a fixed pivot will pro- the proper action. The cam, made by cutting ntinuous groove around its wide perimeter, ounted on a shaft. The groove is formed so it sweeps to one end of the cam face one ion of the way, then swings to opposite end rest of the way. A pin, put into this groove, ld be moved back and forth linearly while the rotates. If the pin is fixed to a lever arm h, in turn, is mounted on a pivot, the re- ocating movement can be utilized to move output gear in and out of drive, as shown gure 5-19.

When the cam is rotated to the position that ws the gear out of engagement, output de- ty will cease. Input will continue unchanged. use of proper gearing and gearing ratios, a ple intermittent drive can be designed for ific active and inactive deliveries.

TECTIVE DEVICES

Protective devices are used on shaft lines to ect the mechanisms that the lines connect.



167.738
Figure 5-19.—Intermittent drive. A. Cam and lever shift; B. Graph of one complete turn of the cam.

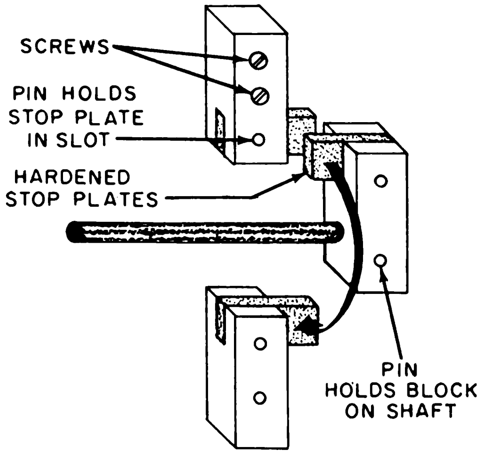
Functionally, a shaft line transmits motion, and the amount a shaft line can rotate by itself is limitless. Moreover, the torque a shaft line can transmit is normally much greater than the torque limit of the mechanisms it connects. The protective devices limit the amount of rotation or the torque of a shaft line. There are many variations to the representative types of protective devices we will discuss. The principles of operation of all the devices in each type, however, are fundamentally identical.

Limit Stops

Limit stops are protective devices for limiting the motion of a shaft line. They are used to prevent shafts from rotating farther than the limits of the mechanisms to which they are connected. Where a shaft line is driven by a servomechanism, such as a director elevation drive, a power limit stop will deenergize the drive before the director arrives at its positive limit of motion. The power stop normally will shift the position of a limit switch. The limit switch will open an electrical circuit causing the power drive to be inactive in the direction of motion towards the positive limit. This prevents the power drive from driving into a positive limit under power. Moreover, the limit switch may energize a circuit to decelerate the drive by applying some form of braking action.

Buffer Stops

Where a shaft line can possess a large amount of momentum, a friction relief or a buffer stop is installed to protect the shaft line and the gearing. A driving friction will relieve the torque on a shaft line by allowing some of the motion to slip out through the friction surfaces. A buffer stop, usually a spring or hydraulic device, will reduce the motion of a shaft line by changing the load on the shaft. The buffer is coupled onto the line just prior to arriving at the positive stop and prevents the line from slamming into the positive stop. A spring buffer will gradually increase the load on the line as the spring is compressed. The com pression of the spring absorbs energy from t line, slowing it down. In a hydraulic buffer t shaft line drives a piston into a cylinder co taining a viscous liquid. The motion of the pisto and hence the shaft line, is resisted by the flo of the liquid in the cylinder.



166.2

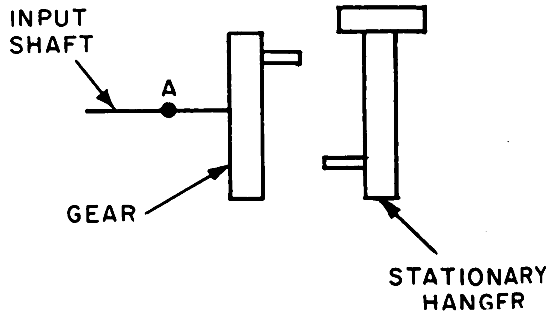
Figure 5-20.—Simple type limit stop.

Positive Limit Stops

A positive limit stop will arrest the moti of a shaft line when the limit is reached. As i name implies it is absolute, bringing the line to dead stop the instant the limit is reached. The are two general classes of positive stops. O limits the shaft motion to 360 degrees or le and the other limits the shaft to a certain numbe of revolutions.

SIMPLE TYPE.—The simplest type of positiv limit stop (fig. 5-20) consists of three metal block with inserted steel stop plates. Two of the block are fastened to the framework of the machine close to the shaft that is to be limited. The thi block is pinned to the shaft. For instance, if t blocks are set to limit the rotation to 180 degree then every time the shaft makes a half turn either direction, the stop plate on the rotatin block touches the stop plate on one of the fixe blocks. This prevents the shaft from rotati farther. The fixed blocks can be set to limit sh rotation to any predetermined value. If one fix limit stop is removed, the shaft will rotate almo 360 degrees.

DOWEL TYPE LIMIT STOP.—Another ex ample of a positive limit stop that limits shaft to less than one revolution is the dow type (fig. 5-21). The stop consists of a dow



167.

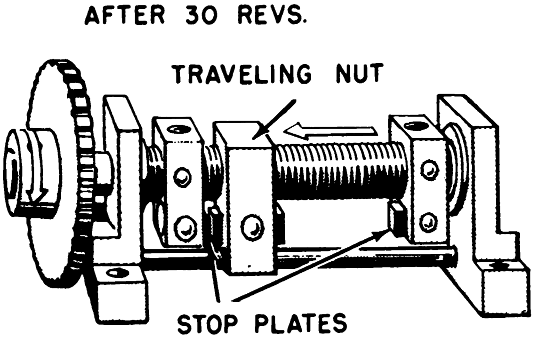
Figure 5-21.—Dowel type limit stop.

mounted on a gear and a dowel fixed to a stationary hanger. The dowels collide to form a positive stop. The solid dot labeled A indicates a clamp adjustment point with which the gear's position relative to the input shaft can be changed.

LEAD SCREW LIMIT STOP.—A third type, as shown in figure 5-22, is often encountered. This limit stop consists of a traveling nut on a threaded screw, a guide rod to prevent the traveling nut from rotating, and two adjusting nuts. The adjusting nuts are pinned to the shaft on either side of the traveling nut, and turn with the shaft. The shaft is stopped from turning when the stop plate on one of the adjusting nuts hits against a stop plate on the traveling nut.

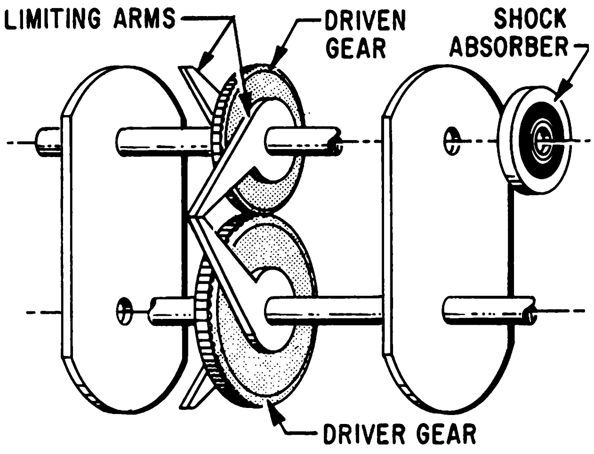
The distance between the adjusting nuts is accurately set, before the stop is installed in the machine, to correspond with the exact number of revolutions the shaft can make before it must be stopped. For example, a line is to be limited to 30 revolutions from its zero position. When the line is at zero the traveling nut will be against one of the adjusting nuts. After 30 revolutions of the line, the traveling nut will have traveled to the other adjusting nut, and the shaft will not be able to turn any farther.

GEAR TYPE LIMIT STOP.—If a gear train is driven by a servomotor, a gear type limit stop can be employed. The gear type limit stop (fig. 5-23), does the same job as the lead screw type, but is constructed differently. It consists of two meshing gears and four limiting arms. When one gear is rotated a given number of revolutions, the limiting arm attached to the driver gear will collide with the limiting arm attached to the driven gear. Reversing direction of rotation of the driver gear will cause the other two limiting arms to collide after the same number of revolutions has been made. The shaft attached to the driven gear is mounted, on one end only, in a rubber housing which acts to absorb the shock of the colliding arms.



12.266

Figure 5-22.—Lead screw limit stop.



167.51

Figure 5-23.—Gear type limit stop.

The limiting arms are factory preset to collide after a given number of revolutions (dependent upon gear ratio.) Therefore, the adjustment will normally consist of setting dials and gear trains to the stops in accordance with prescribed adjustment procedures.

Limit Switches

The electric switch is familiar to you. You know that it is a type of mechanism used to turn electric power on and off, or to switch electric current from one circuit to another. It would be a simple matter to fasten a couple of contactor arms to the traveling nut of a lead screw limit stop unit (fig. 5-24) and to mount a pair of on-off electric switches to be actuated when contacted by the blades. The electric switches could be set to control the operation of the mechanism between the prescribed limits, and the mechanical (positive) stops set somewhat beyond them. Normal operation would be within the limits of the electric switches. In the event of a defective switch, short circuit, or other reasons which would allow the mechanism to run beyond the electric switch limits, the mechanical

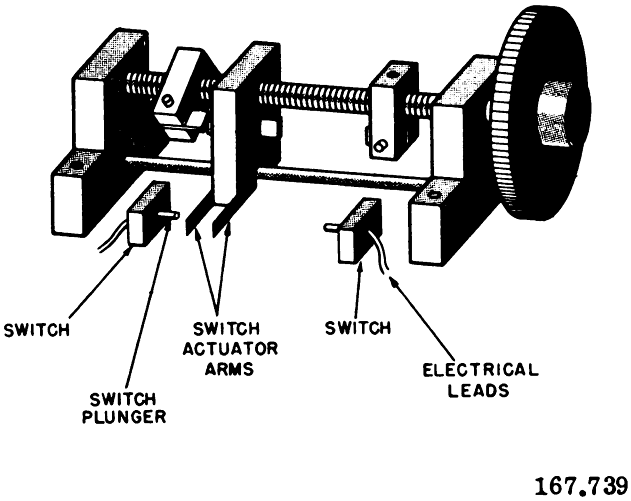


Figure 5-24.—Limit switches.

stops would be brought into play as a safety or protective feature.

The Shock Absorber

The shock absorber used in a computer is really just a special type of coupling. It has provisions for absorbing shock which distinguish it from other couplings. Briefly, it consists of a clamp coupled to a gear by a spring and arm arrangement. The clamp fastens the shaft to the hub of the gear (fig. 5-25).

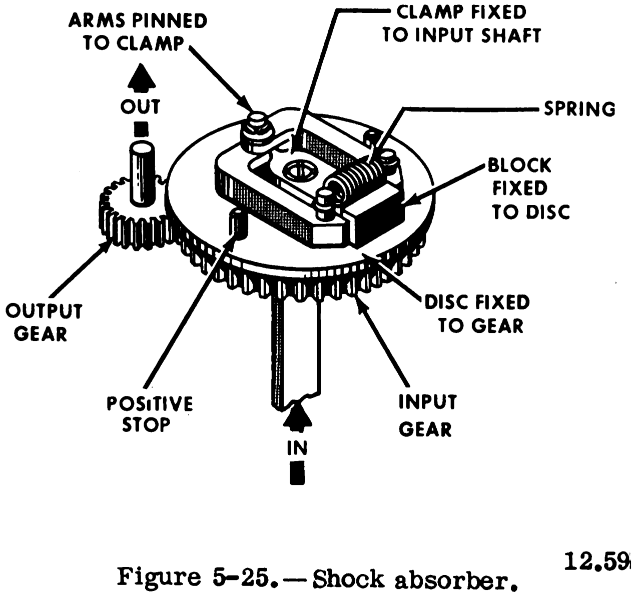


Figure 5-25.—Shock absorber.

Follow the action in figure 5-25. To start with, the input shaft turns the input-gear hub clamp. The arm ends push the block, which is fixed to the disc that is fixed to the input gear. In turn, the input gear drives the output gear and output shaft. The thing to visualize is that the arms give against the spring to absorb the shock when the input shaft is started suddenly. That's the trick to the whole works.

Take a look at the disassembled view of the shock absorber in figure 5-26. It shows you exactly how it is constructed. There are two important things to see in the figure. First, note that the hub is free to rotate in the gear and is mounted on ball bearings. And second, note that the clamp fastens the hub to the input shaft. Then, when the clamp is attached to the hub, the arms are stretched against the spring to sandwich the block on the disc. The two positive stops simply stop the arms to keep the spring from overstretching.

Friction Relief Drive

A friction relief drive is special shaft line coupling which will slip when the torque on the line is too great. This device protects the gearing and mechanisms on the line from damage from an excessive amount of torque. The construction of a typical friction relief drive is shown in figure 5-27. The gear is free to turn on the input shaft. Friction disks are cemented to both sides of the gear. The flanged hub is pinned to the shaft and rotates with it. The hub is in contact with the friction disk on top of the gear. The sliding flange is connected by a tongue and groove arrangement to the collar which is pinned to the shaft. The sliding flange is pressed against the bottom friction disk on the gear by spring pressure. Hence the gear is sandwiched between the two flanges by spring pressure. The compression of the spring may be adjusted by the clamp which can be screwed on the threaded sleeve when the clamp is loose. The output of the drive is taken from the gear.

The connection between the input shaft and the output gear of the drive is the friction coupling between the flanges and the gear. The friction is adjusted so that under normal conditions the gear will turn with the shaft. But if the torque is greater than normal, or if there is a restriction on the line, the friction drive will slip before any damage is done. For example, a shaft line with a limit stop which is at one of its limits is mechanically restrained at that value. An attempt to force the line

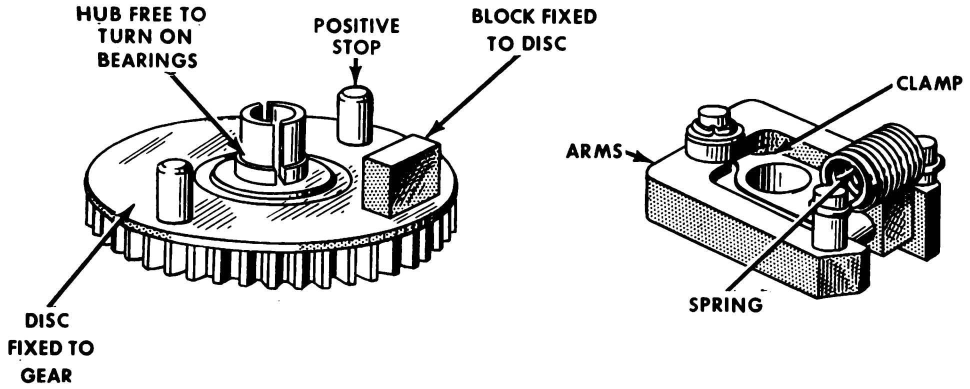


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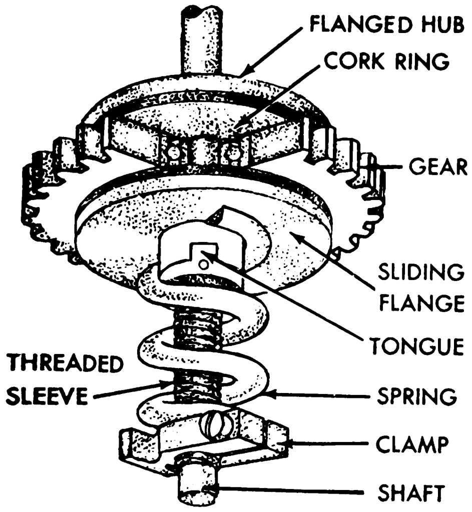
Figure 5-26.—Shock absorber, disassembled view.



12.267

Figure 5-27.—Friction relief drive.

beyond the limit could damage the mechanisms. But a friction relief drive in the line will allow the motion to slip and relieve the torque on the line.

DIALS AND COUNTERS

Dials and counters are installed to measure the rotation of shafts and indicate the value of the quantity being transmitted by the shaft. Fire control quantities are represented in mechanical equipment by shaft value and total shaft value. To set-in or read-out a quantity in a mechanical instrument, you must have some means of measuring the position of the shaft with respect to a reference. The reference position of the shaft usually represents the zero value of the quantity being transmitted.

Dials

Shaft angles are often indicated on two different dials. One is called the low-speed or coarse dial, and the other the high-speed or fine dial. The speed refers to the ratio between the dial and the quantity whose motion it indicates. Thus a one-speed dial that indicates director train angle will make one revolution when the director turns one complete revolution. This dial can be read to about one degree, but the graduations are too close together to permit accurate reading to fractions of a degree. The high-speed train dial makes 36 revolutions for each revolution of the director, or one revolution for each 10 degrees of director motion. The degree marks are thus 36 times as far apart, and the dial can be read to one or two minutes of arc.

The high-speed dial repeats the same position and reading 36 times during one revolution of the director. Thus this dial must be used in combination with a low-speed dial. The two dials can be compared with the two hands of a clock. The low-speed dial corresponds to the hour hand which runs at two speed (two revolutions per day). This hand tells the hour but does not divide it accurately. The high-speed dial corresponds to the minute hand which runs at 24 speed (24 revolutions per day). This hand shows the exact minute of the hour, but does not show which hour.

The various pairs of dials in fire control equipment run at different combinations of speeds. For a part which cannot make a complete revolution, for example an elevation indicator, a two-speed or four-speed dial may be used as the low speed dial. Where great accuracy is required, the high-speed dial may operate at 72 speed or some higher multiple. Where accuracy is not critical, a single low-speed dial is used. Where a quantity may have either a positive or negative value-elevation for example—the color of the dial markings is often used to indicate polarity. White markings are used when the quantity is positive; red markings indicate negative value.

Figure 5-28 shows a dial arrangement which can be used to indicate true target bearing. True bearing is the sum of target bearing and own ship's course as shown in figure 5-28A. The synchro in figure 5-28B receives own ship's course and turns the inner dial through this angle. In the example shown in the figure, the dial is turned 70° clockwise. The outer ring dial is turned in a counterclockwise direction through an angle of 50°, which is relative target bearing. By reading the graduations on the ring dial against the arrow of the inner dial, the sum of the two angles, 120° (which is true target bearing), can be read.

Counters

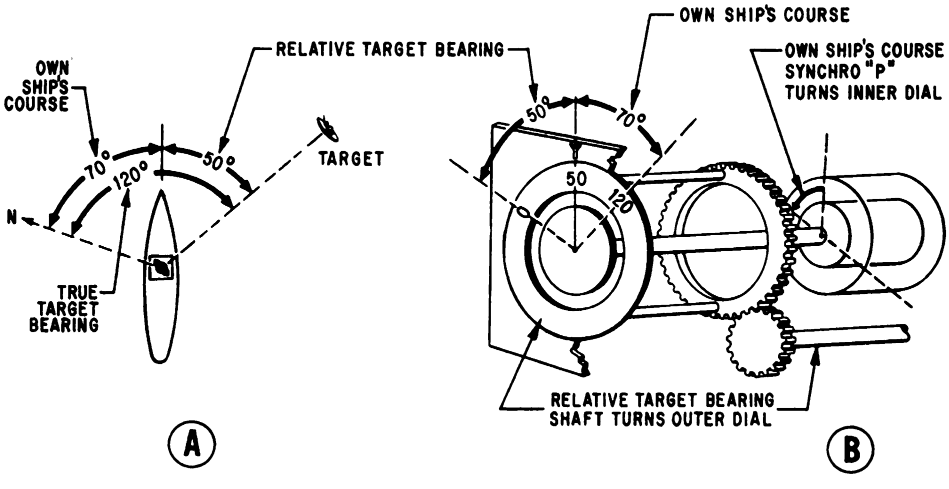
It sometimes becomes necessary to count shaft revolutions.

No doubt you have seen counters used in automobiles to indicate mileage. Well, the counters used in fire control work on the same principle. But instead of indicating mileage, they count the revolutions of a shaft. The value that a shaft carries might be any value used in computing the fire control problem, such as yards of range, degrees of bearing, or target speed in knots.

Figure 5-29 shows a counter connected to a shaft by miter gears. In this case the counter serves a dual purpose: first, it is used for indicating proper adjustment; and second, it indicates shaft revolutions.

To perform an adjustment on the setup (fig. 5-29), first set the computing device at its zero position. Then loosen the clamp at the counter and turn the counter until it, too, reads zero, and tighten the clamp. Now both the computing device and the counter are at their zero position.

Next, loosen the clamp at one end of the sleeve coupling and turn the input quantity until it and the counter are on zero at the same time. Finally, tighten the clamp of the sleeve coupling to complete the adjustment.



12.275

Figure 5-28.—True bearing dial.

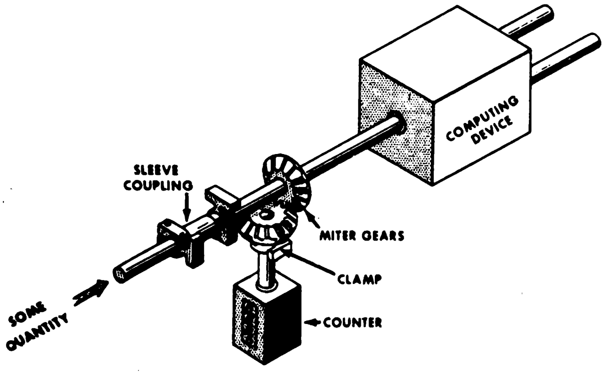


Figure 5-29.—Counter. 12.61

This type of counter is called an off-line counter, as it can be disconnected without affecting the adjustment.

ELECTROMECHANICAL COMPONENTS

SWITCHES

A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is used. Because it is placed in series, all the circuit current will pass through the switch. Because it opens the circuit, the applied voltage will appear across the switch in the open position. Switch contacts are opened and closed quickly to minimize arcing; therefore, switches normally have a snap action.

Many types and classifications of switches have been developed. A common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals connected to the movable element of the switch. The number of throws indicates the number of contacts each pole can make. The number of positions indicates the number of places at which the operation device (toggle, plunger, etc.) will come to rest. Figure 5-30 presents the schematic diagrams of some often used switches.

An example of a switch position is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a two-position switch. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circuit is called a single-position switch. If the toggle switch will come to rest at any of three positions, it is called a three-position switch.

Another means of classifying switches is the method of accuation; that is, toggle, pushbutton, precision and rotary types. Further classification can be accomplished by a description of switch action such as on-off, momentary on-off, on-momentary off, and so forth. Momentary contact switches hold a circuit closed or open only as long as the operator deflects the actuating control.

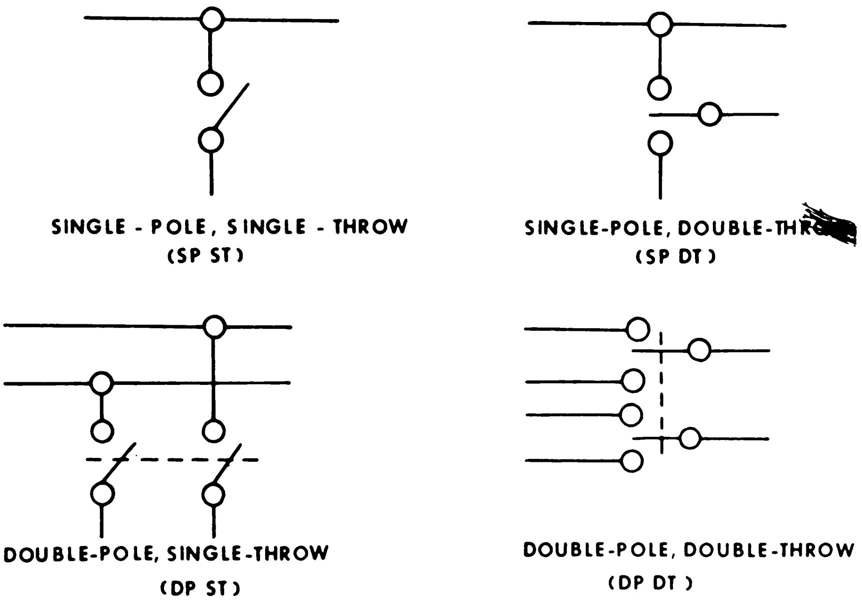
Switches are rated according to their current-carrying capacity at a specific voltage. The current rating depends on the cross-sectional area of the contacts. The voltage rating depends on the space between the contacts.

Manual Switches

TOGGLE SWITCHES.—Toggle switches are one of the most common types of manual switches. Toggle switches have their moving parts enclosed. A double-pole, double-throw, on-off-on toggle switch is shown in figure 5-31. These switches have many uses and are used extensively for applying power to various circuits, such as low voltage power supplies.

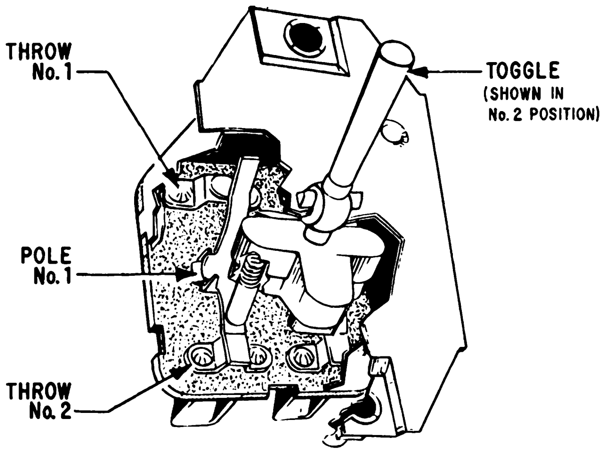
PUSHBUTTON SWITCHES.—Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the pushbutton by an insulator. This switch is usually spring loaded and is of the momentary contact type. These switches have many uses, such as indicator light checks and motor start and stop circuits. Typical arrangements of pushbutton contacts are shown in figure 5-32.

ROTARY SELECTOR SWITCHES.—Rotary selector switches may perform the functions of a


SINGLE - POLE, SINGLE - THROW
(SP ST)
SINGLE-POLE, DOUBLE-THR[illegible]
(SP DT)
DOUBLE-POLE, SINGLE-THROW
(DP ST)
DOUBLE-POLE, DOUBLE-THROW
(DP DT)

12.66

Figure 5-30.—Commonly used switches; schematic diagram.



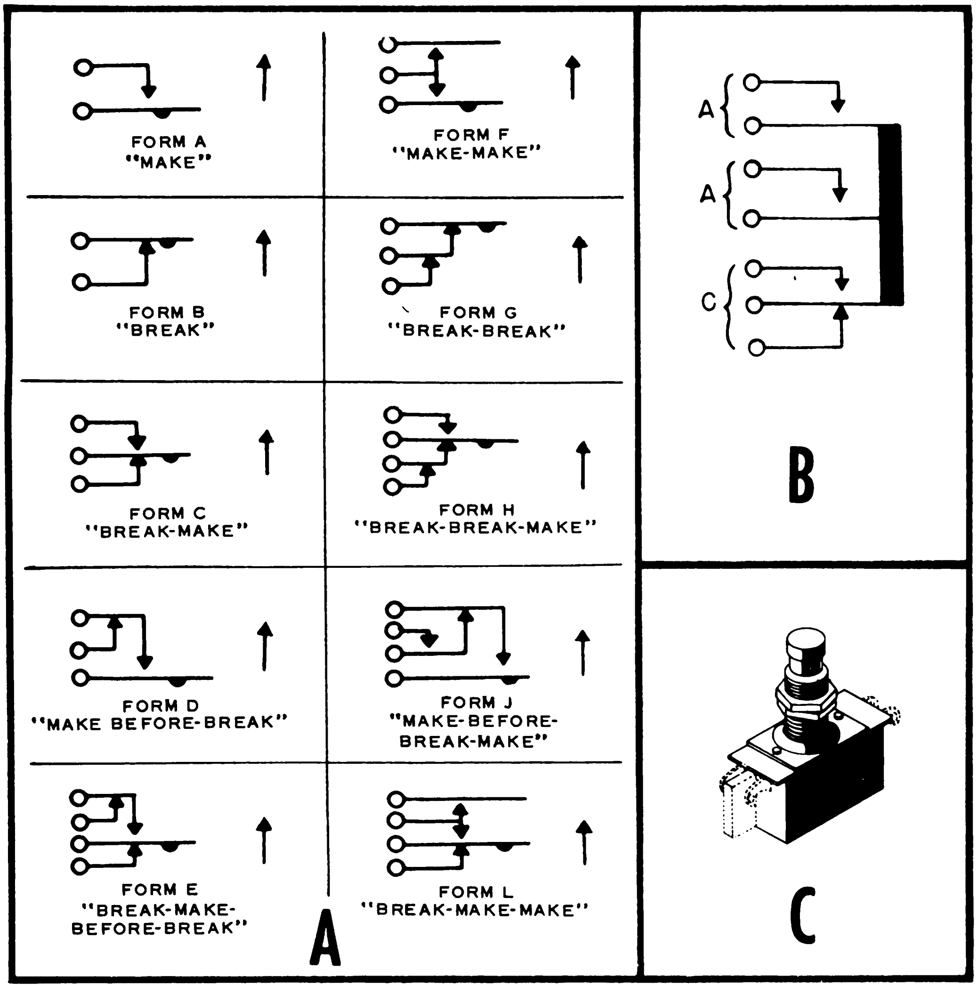
12.67

Figure 5-31.—Toggle switch, double-pole, double-throw.

number of switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. See figure 5-33. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. Voltmeter range selector switches are examples of this type.

SNAP SWITCHES.—The snap switch (fig. 5-34) is a device that opens or closes a circuit with a quick motion. A rotary snap switch consists of one or more sections each of which has a rotor and a stationary member (fig. 5-35). A shaft with a handle at one end extends through the center of the rotors. The rotors are snapped in and out of the stationary contacts on the pancake sections. When the handle is turned, it first winds a coil spring on the shaft. As the handle is turned farther, the coil spring snaps the rotor contacts in or out of the stationary contacts.

Snap switches are available in a wide variety of current ratings, poles, movements, and circuit arrangements. Most of these switches are suitable for operation on a.c. at 600 volts and d.c. at 250 volts. Snap switches are used extensively in the distribution sections of switchboards, to connect the power supplies to the various buses.



1.99(12)

Figure 5-32.—Pushbutton switches.

TYPE-J MULTIPOLE ROTARY SWITCHES.—'he type-J multipole rotary switch consists of an qual number of rotors and pancake sections ig. 5-36). The number of sections required in he switch is determined by the individual applicaion. A shaft with an operating handle extends hrough the center of the rotors. The movable ontacts are mounted on the rotors, and the tationary contacts are mounted on the pancake ections. Each section consists of eight contacts, esignated A to H, and a rotor having two insulated novable contacts spaced 180° apart. Each movble contact is arranged to bridge two adjacent tationary contacts. The switch has eight posiions. A detent mechanism is provided for proper linement of the contacts in each position of the operating handle. In one position, the rotor contacts bridge segments A-B and E-F. In the next position, the rotor contacts bridge segments B-C and F-G. Diagonally opposite pairs of contacts are subsequently bridged for the remaining positions. The various circuit leads are connected to the proper pancake terminals and the transfer of circuits is effected by operating the handle.

JR SWITCHES.—The JR switch shown in figure 5-37 is installed on Fire Control (FC), recent Interior Communication (IC), and Action Cutout (ACO) switchboards.

This switch is smaller in size and more readily disassembled than the J switch. These

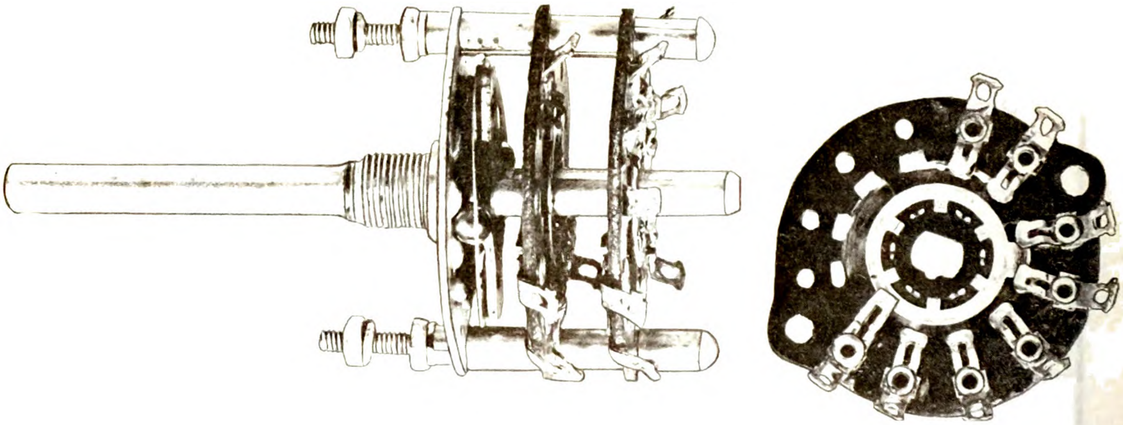

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Figure 5-33.—Rotary selector switch.

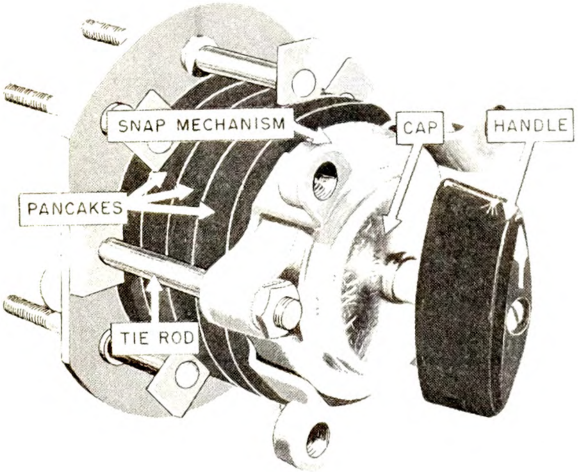

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Figure 5-34.—Snap switch.

features result in a saving in switchboard space and facilitate repairs. The JR switch is of the 1JR, 2JR, 3JR, or 4JR type.

The 1JR switch has only one movable contact per section. This movable contact bridges two adjacent stationary contacts.

The 2JR switch is the same electrically as the J switch, and is the type used for general applications.

The 3JR switch utilizes one of the stationary contacts as a common terminal. This stationary contact is connected in turn to each of the other stationary contacts of the section by a single wiper contact. The 3JR type is used for selecing one of several (up to seven) inputs.

The 4JR switch has two movable contacts per section. Each movable contact bridges three adjacent stationary contacts (fig. 5-37B). This switch is used to select either or both of two synchro indicators. The positions of the switch are:

90° right—both indicators energized
45° right—indicator 1 energized
0°—off
45° left—indicator 2 energized

When the 4JR switch is in the OFF position, both indicators are connected together but are disconnected from the power supply.

The designations of JR switches are determined by the type of section followed by the number of sections in the switch. For example, a 2JR10 switch denotes a JR switch having 10 type-2JR sections.

Automatic Switches (AJR)

Recent FC switchboards employ automatic switches that can be controlled from remote

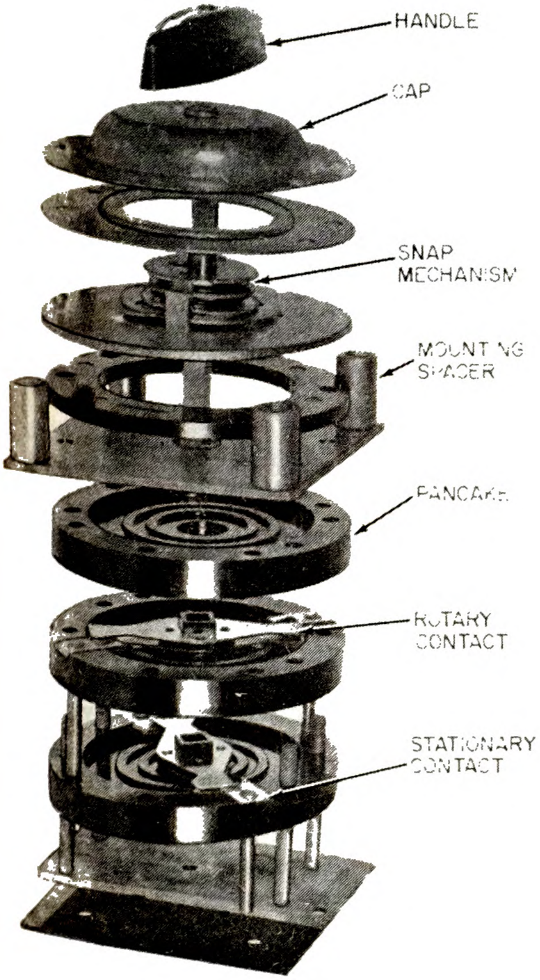

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Figure 5-35.—Snap switch, exploded view.

stations. These switches are similar in construction to the manually operated switches but have a servosystem to control the switch position. Figure 5-38 shows a simplified diagram to illustrate the operation of an automatic switch. The control voltage is supplied by the two autotransformers, one located at the remote station, and the other at the switch. If the wiper arms of the two transformers are at the same numbered tap, there will be no potential difference between the taps, and no current will flow through the control winding of the motor. If the wiper arm at the remote station is repositioned, there will be current flow in the control circuit. The motor will drive, changing the position of the switch and the other wiper arm. The motor will drive until the two wiper arms are at the same potential, at which time the switch will be at the desired position.

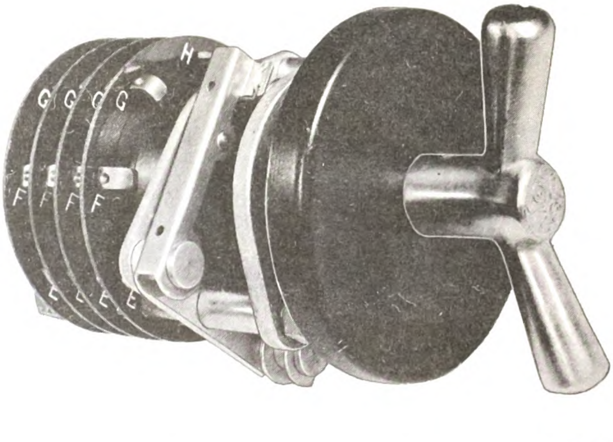

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Figure 5-36.—Type-J switch.

RELAYS

General Purpose Relays

Relays are electrically operated switches that are classified according to their use as control relays or power relays. The POWER RELAYS are the workhorses of electrical systems. As such, they control the heavy power circuits.

The function of a CONTROL RELAY is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. For example, control relays are used to start and stop electric motors. The heavy power relays that actually apply the power to the motor are the MAIN LINE CONTACTORS. The relays that control the main line contactors are control relays.

The use of relays saves space and weight in the ship by permitting the use of small switches

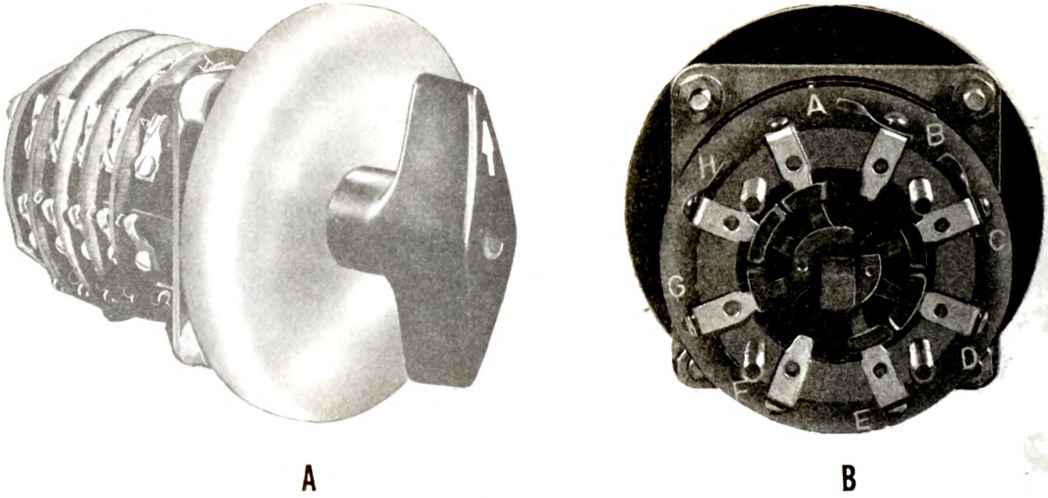

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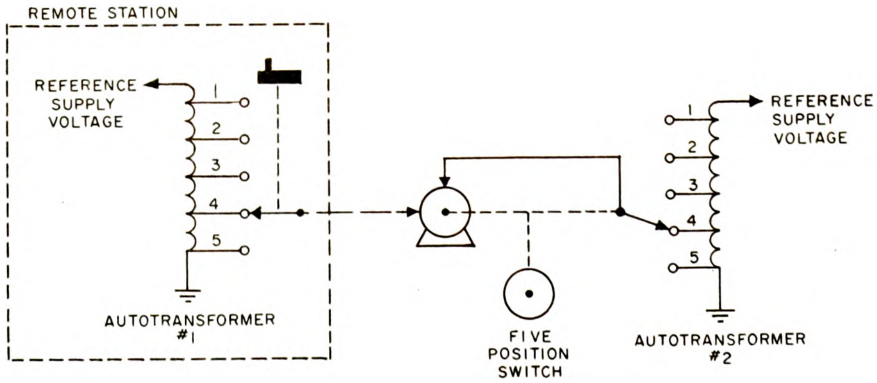
Figure 5-37.—Type-4JR switch.

at remote control stations. These switches permit the operator to control large amounts of current at other locations in the ship, and the heavy power cables need to be run only to the point of use. Only light weight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays find many other uses. With these, electron tube plate currents can control the larger currents necessary to operate electrical devices. They find extensive use in weapon direction equipment circuits, where a small electric signal sets off a chain reaction of successively acting relays performing various functions, such as target designation and weapon assignment. Control relays can also be used to prevent certain functions, such as the movement of a launcher, or missile firing, from occurring at the improper time. Various electrical operations in the equipment which must not occur simultaneoulsy can be "interlocked" by control relays.

Another possible classification of relays is open, semisealed, and sealed. Semisealed relays have protective covers and are gasketed against entrance of salt, dust, and foreign material into the contact or mechanism area.

For other applications in today's far-ranging ships, however, it is necessary to go beyond the



167.52

Figure 5-38.—Automatic switch servosystem.

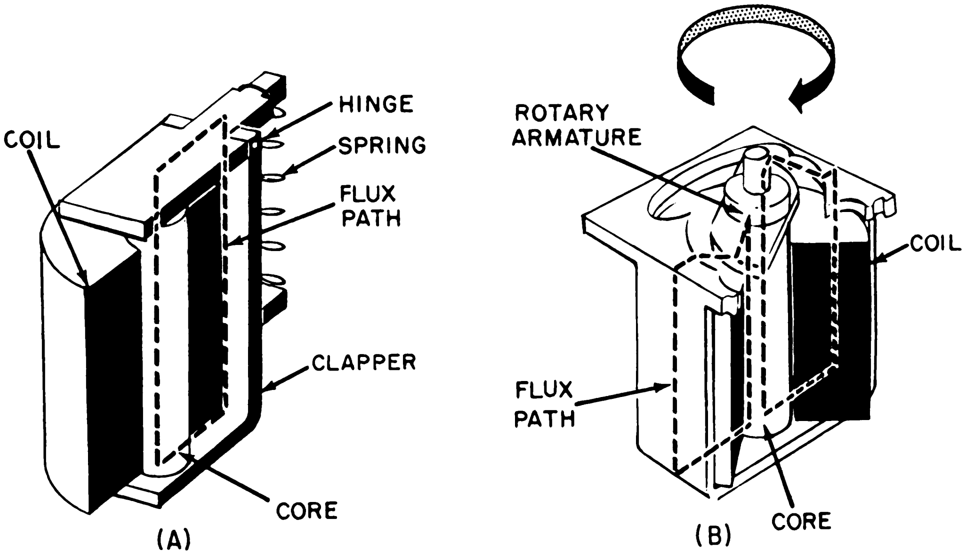
protection offered by the open type and the semisealed relays. When such relays are used, quick changes in climatic conditions (humidity and temperature) can cause condensation of water vapor within the unit. Subsequent low temperature will then freeze the moisture on the contactor, with a resultant inability to carry electric current.

Hermetically sealed relays were developed to answer the demands of most modern equipment. A true hermetic seal is generally considered one that is metal-to-metal or glass-to-metal. Plastic or plastic-rubber type gasket seals are not generally considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. There are applications where a gasket type sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more permanent. The hermetically sealed relay also has the advantage of being protected from improper adjustments.

In general, the basic components of a relay are the coil or solenoid, the iron core, the fixed and movable contacts, and the mounting (and if sealed, the can). A manual switch, limit switch, or other small control device starts and stops the flow of current to the coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field moves a clapper or plunger which completes the magnetic circuit. Figure 5-39A shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux.

The second basic type of relay is the rotary (fig. 5-39B). Although this type of construction is not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. The disadvantage is that they are somewhat sluggish and require higher operating power for many purposes. The rotary relay operates on the principle of an electric motor, but through only a small arc. The problem of hanging contacts on such a mechanism is a difficult one, and therefore the use of these devices is limited to applications where high shock warrants the larger size and weight. When used with standard wafer switch assemblies, this type of relay provides a means for assembling a switching device of any degree of complexity.

You will encounter relays operating from an a.c. supply; they depend on the same fundamental principles as the d.c. relay; that is, magnetic fields. When a.c. is applied to an electromagnet, the current will pass through zero twice in each cycle. Since the pull on the armature is proportional to the current through the electromagnet, the armature tends to open



12.73

Figure 5-39.—Basic types of relays.

every time the current nears zero, causing chatter. To remedy this, shading coils (sometimes called shaded poles) are used.

A shading coil consists of a copper band or stamping which is short-circuited and embedded around part of the electromagnet pole face. By being placed around part of the pole face, it acts as a shorted transformer secondary. The current in the main coil lags the applied voltage by approximately 90° and the flux is in phase with the current. The voltage of the shading coil is induced voltage and lags the current in the main coil by 90 degrees. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90 degrees. This means that flux will exist in the electromagnet even when the main coil current becomes zero. Thus, chattering is prevented.

The arrangement of relay contacts has many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement. Figure 5-40 shows the basic relay contact groups which form the basis for the various arrangements.

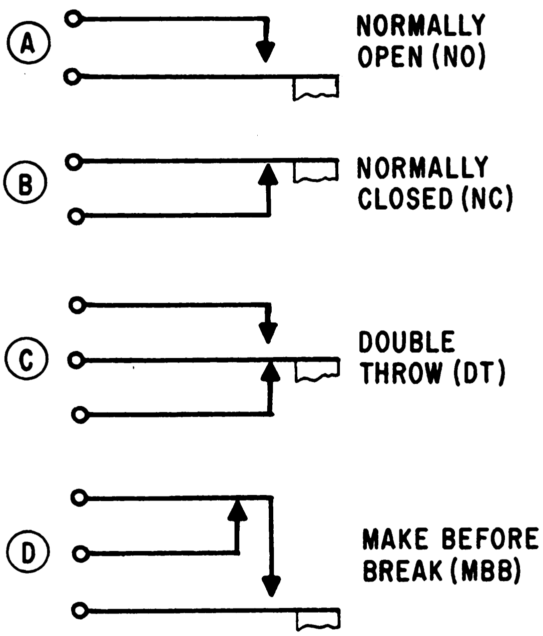


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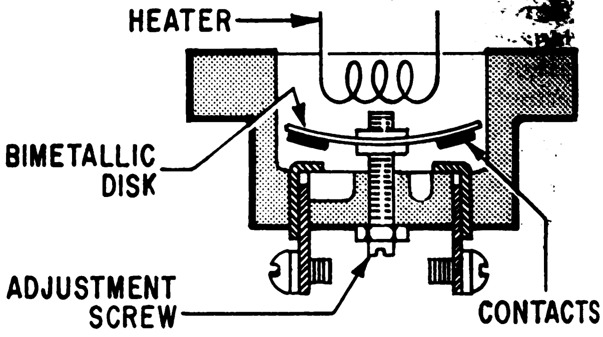
Figure 5-40.—Basic relay contact groups.

Special Purpose Relays

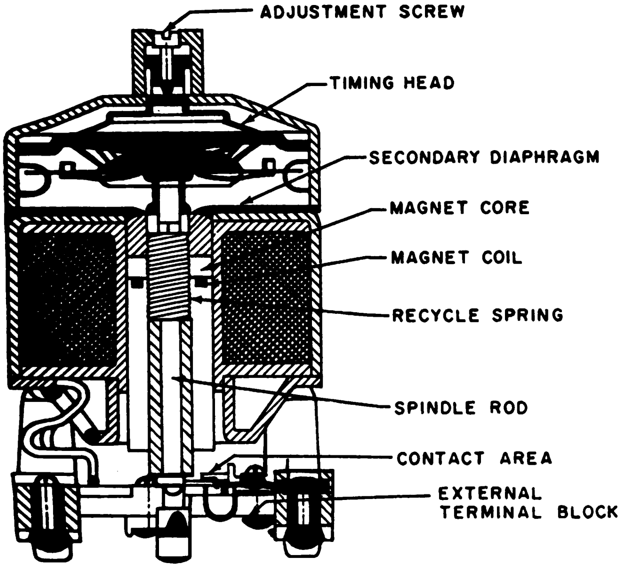
THERMAL RELAY.—It is often desirable to introduce time delays by use of relays. One method is to use a thermal relay for a time delay (fig 5-41). When current is applied to the heater, heat is transferred to the bimetallic disk. The bimetallic disk consists of two layers of dissimilar metals. These dissimilar metals have different expansion coefficients. In other words, the heat causes unequal expansions of the two metals. This causes the upper contacts to move downward until they make contact with the lower contacts. Many thermal relays are sealed units and the time required to close the contacts is a design feature of the relay. The relay of figure 5-41 provides an adjustment screw with which you can change the gap between the upper and lower contacts. Increasing the gap increases the time delay. Because its mechanism is simple, the thermal relay can be made very small and hermetically sealed, making it ideal for use in fire control equipment. Because the thermal relay is activated by heat, it can be used on either alternating or direct current.



5.82A

Figure 5-41.—Thermal relay.

DIAPHRAGM AND MOTOR DRIVEN RELAYS.—Energizing the magnetic coil of the diaphragm type relay (fig. 5-42) causes the relay spindle rod to move. Movement of the spindle rod exerts a pull on the timing head, a diaphragm with a small orifice at its center. The movement of the



167.54
Figure 5-42.—Diaphragm type relay.

timing head is opposed by air pressure which slowly reduces due to air passing through the timing head orifice.

The reduction in air pressure allows the spindle rod to slowly overcome the restraining action of the timing head. Movement of the spindle rod will eventually cause the relay contacts to make or break. (The relay can be designed for a slow make-fast break or fast make-slow break). The adjustment screw provides a means of modifying the timing head orifice which speeds up or slows down the action.

Another form of time delay relay is the motor-driven relay. With this type of relay, the contacts are positioned by a constant-speed motor driving through a suitable gear train. Normally an adjustment is provided as a means of changing the time required to make or break relay contacts. Automatic resetting may immediately take place or it may be delayed until the next delay cycle is started.

CLUTCHES

A motor often drives more than one line of shafting, and situations arise in which one or another of the lines must be stopped without stopping the other lines. A simple solution would be to have a severed shaft. To drive, the ends would have to be pressed together so that frictional force would enable the shafts to rotate together, figure 5-43.

However, since the surface area of the two ends is small, the torque transmitted is also relatively small. Torque is a function of: (1) the force with which the butting ends are together, (2) the surface area, and (3) the friction characteristics of the material involved.

Disk Drive

By attaching disks to the shaft ends, the surface contact area is increased, thus increasing torque. Further increases can be brought about by using a material with a high coefficient of friction on the contacting surfaces, figure 5-44.

Such disks require that they be thrust firmly together to drive without slipping. Pinning a key to one shaft and slotting its disk to permit it to slide longitudinally on shaft and key would provide a quick means of engagement or disengagement. By using a simple lever (refined perhaps by adding a roller and spring to hold the disk under tension in the selected position), the sliding disk could be moved to disengage it or be forced into good driving contact with the other disk. Each line of shafting so equipped could be engaged or disengaged as desired, without interfering with the other lines. This type of clutch may be used at very high speeds, although it is subject to slippage.

Toothed Jaw Clutch

With toothed or serrated jaws, engagement can be achieved rapidly without exact shaft position alignment, at high speed, and with heavy loads. It is a locking type of clutch

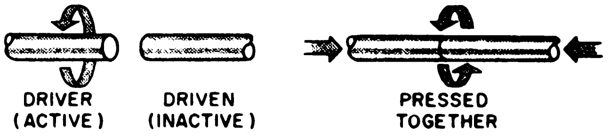


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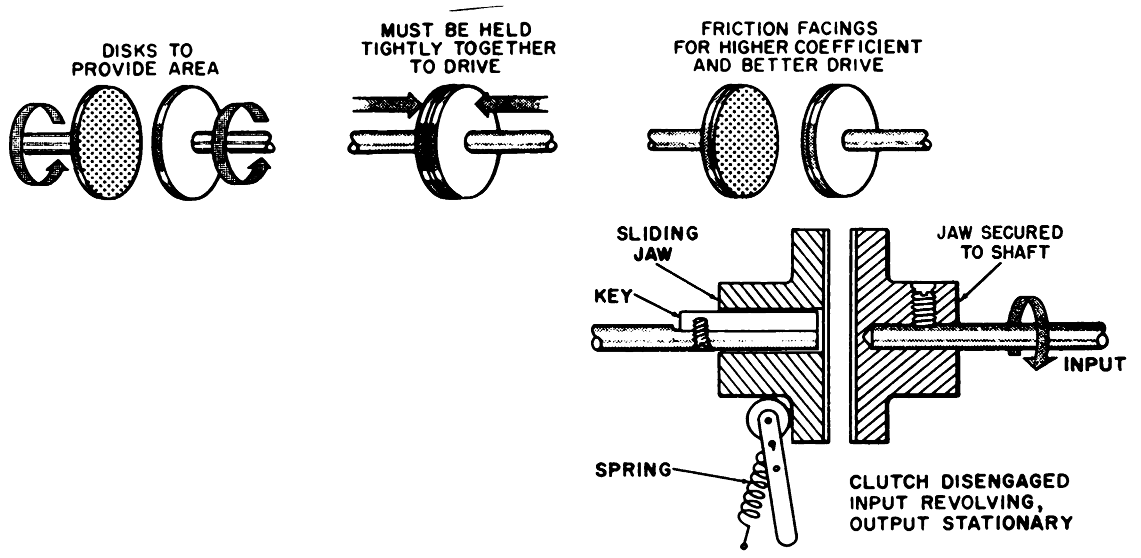
Figure 5-43.—Frictional force.


DISKS TO PROVIDE AREA
MUST BE HELD TIGHTLY TOGETHER TO DRIVE
FRICTION FACINGS FOR HIGHER COEFFICIENT AND BETTER DRIVE
SLIDING JAW
JAW SECURED TO SHAFT
KEY
INPUT
SPRING
CLUTCH DISENGAGED INPUT REVOLVING, OUTPUT STATIONARY

167.741

Figure 5-44.—Disk drive.

permitting no slippage. Revolutions of the output side will equal those on the input side. Some means are needed to control jaw movement for engagement or disengagement and, when coupled, exert force necessary to keep the jaws together. A simple toothed jaw cluth would look something like figure 5-45.

By keeping one jaw slidable on the shaft and providing a yoke, we would have a manually controlled mechanical means of engaging or disengaging the clutch.

The Solenoid Clutch

The solenoid offers the electrical means of connecting or disconnecting a drive. The solenoid clutch is comprised of cylindrical jaws (fig. 5-46) with serrated mating edges within a solenoid coil. One jaw is secured to the input drive shaft and revolves with it. The other jaw is mounted on a hub and made so it will slide longitudinally on the shaft, moving on a key or in a slotted section.

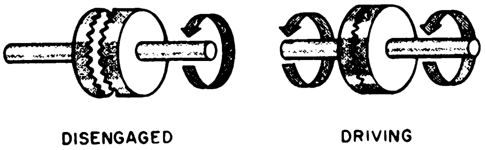


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Figure 5-45.—Toothed jaw clutch.

A spring (or spings) keeps the jaws apart and out of engagement when the solenoid is not energized. Energizing the solenoid magnetizes both jaws, and the slidable output jaw is pulled into contact with the input jaw. As long as electric current is supplied to the solenoid, the magnetic field is maintained and the jaws are held in engagement. Power is transmitted throug the clutch to the output shaft without slippage. When electric current is turned off, the magnetic field ceases and the springs withdraw the sliding jaw. With application of electric current, jaw reaction is almost instantaneous. This rapid certain clutch connect or disconnect action makes the solenoid clutch a favored means of contro in high-speed equipment.

Magnetic Clutch

The magnetic clutch is used to govern the velocity of the driven shaft or the amount of loa it will cary. An electrical signal to a windin of the magnetic clutch (fig. 5-47) creates magneti fields about the coupling surfaces; the strengt of these fields determines the amount of slippag in the clutch. The principles of operation of thi type clutch are similar to those of a frictio

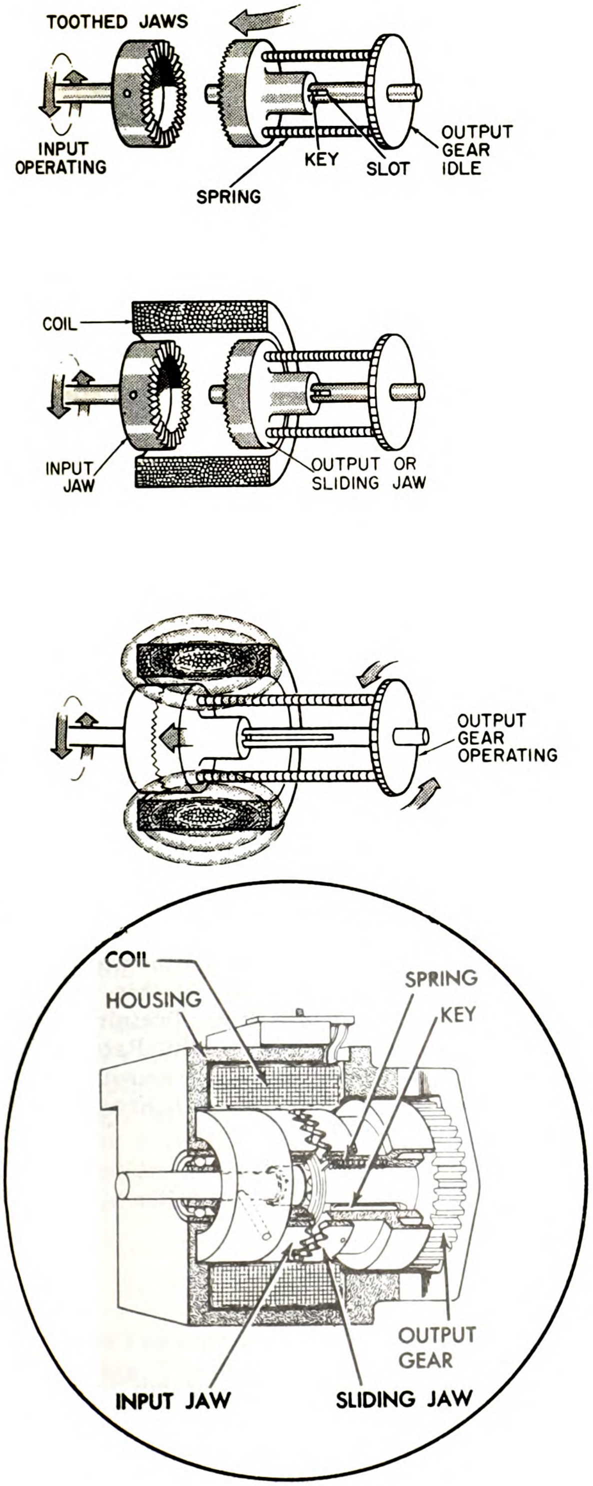

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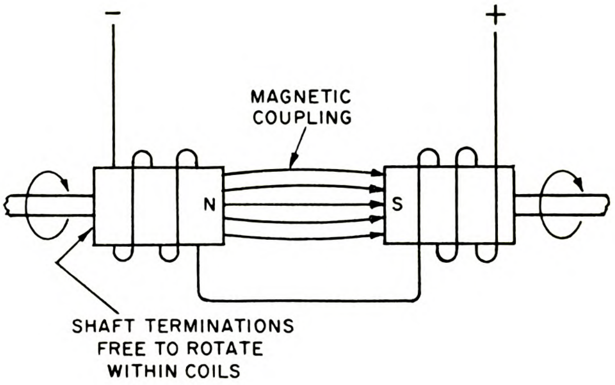
Figure 5-46.—Solenoid clutch.



167.55

Figure 5-47.—Magnetic clutch.

relief drive except that the coupling is controlled by magnetic fields rather than mechanical friction surfaces.

The distance between the coupling surfaces in figure 5-47 is exaggerated. In an actual application, the surfaces are quite close to one another.

LOCKS AND BRAKES

A solenoid lock works like the solenoid clutch, except one jaw is pinned to the housing. The other jaw is keyed to the hub of the input gear both of which can slide on the input shaft, and are free to turn as long as the solenoid coil remains deenergized. The gear is the input in this assembly, figure 5-48.

Energizing the coil draws the sliding jaw along the gear hub, locking it to the pinned jaw and preventing any further motion of the input gear or its associated parts. This device is used where a quick-acting lock is required to stop the equipment and hold it immobile as long as current is applied to the coil.

The relation between the electrical signal and the mechanical line's connection is determined by the length of time the electrical signal is required. If a shaft must be uncoupled most of the time, the electrical signal to the clutch will be used to couple the shaft. Of course the

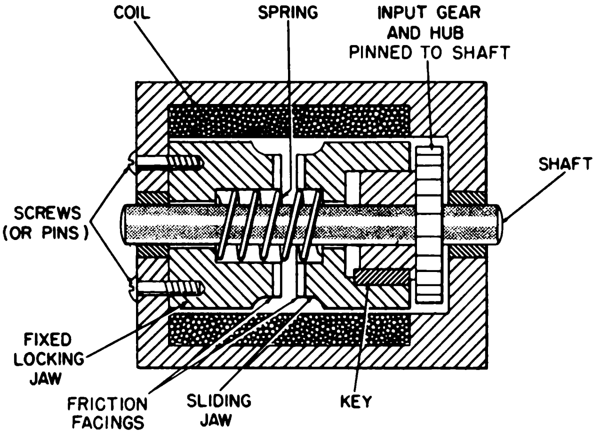


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Figure 5-48.—Solenoid lock.

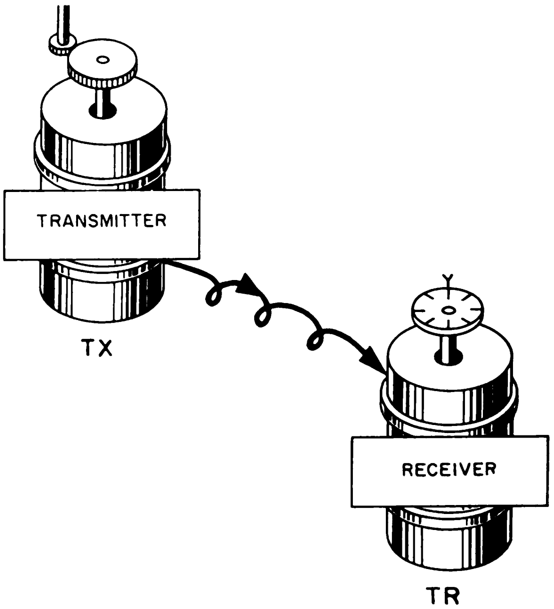
opposite is true; if a shaft must be coupled most of the time, the signal to the clutch will be used to uncouple the shaft.

The solenoid lock is often used in conjuction with a solenoid clutch. When the clutch disengages, the solenoid lock is brought into play (by means of electric switching circuitry) locking that part of the mechanical equipment in its exact disengaged position.

SYNCHROS

It takes a lot of information to solve the fire control problem. This information must be sent back and forth between equipment located at considerable distance from each other. For example, a missile fire control computer needs own ship's heading, target range, bearing, and elevation to solve the fire control problem. Own ship's heading comes from the master gyro compass. Target bearing, elevation, and range come form a director or radar set. All of these basic quantities are supplied by equipment located at distances of a few feet to possibly several hundred feet from the computer. Therefore, some sort of data transmission system is needed.

Fire control information is transmitted electrically between distant stations by synchro system (fig. 5-49).



12.156

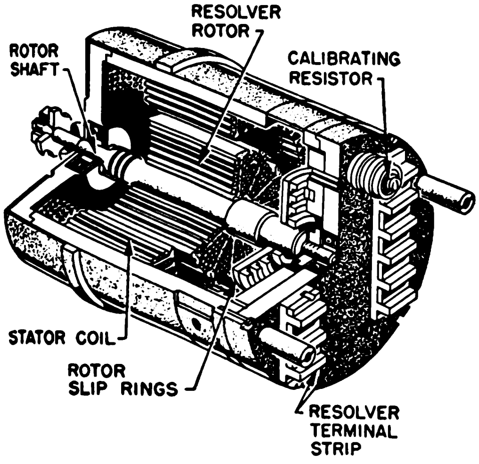
Figure 5-49.—Elementary synchro system.

Obviously, a thorough knowledge of synchros and their circuits is necessary for the FTM. The groundwork has been laid in Basic Electricity, NavPers 10086-B. The construction and theory of operation of various synchros are covered in chapter 21 of Basic Electricity; we will not repeat that information here. At this point, you should review the basic Rate Training Manual coverage of synchros. Later in this Rate Training Manual, we will amplify your knowledge concerning the application of synchros as data transmission devices.

RESOLVERS

Construction

Basically, a resolver (fig. 5-50) is a transformer in which the secondary windings can be rotated with respect to the primary windings. Consequently the amount of magnetic coupling between the primary and the secondary is variable. In its most common form it consists of a stator and a rotor, each having two separate windings placed precisely at right angles to each other



12.106
igure 5-50.—Cutaway of transformer resolver.

fig. 5-51A). Most schematic diagrams of re-olvers show only the active windings; therefore, f three windings are used in a particular ap-lication, the diagram will show these three. Since the two stator windings are physically nd electrically at right angles to each other, if n a-c voltage is applied to the winding there vill be no magnetic coupling between them. The tator windings are mounted on the resolver ousing and are stationary with respect to it. xternally, a resolver resembles a motor or enerator, and is a low impedance element.

The rotor windings of the resolver are wound t right angles to each other. Hence there is no nagnetic coupling between the two windings. The otor windings are mounted on the rotor shaft nd will turn with it. The rotor is capable of nlimited rotation. Thus the rotor windings can be et at any angle with respect to the stator windings.

peration

A resolver has both electrical and mechanical rotation) inputs. The outputs will be proportional o the product of the electrical input and either he sine or cosine of the angle through which the otor has been turned. Figure 5-51B, C and D hows the rotor in three different positions with espect to that stator. The stator is supplied vith a fixed voltage which we will assume to be nity. Since similar action takes place in all the vindings, only one set is shown for clarity.

In figure 5-51B, the rotor and stator windings have an angle of 0° between them. With the rotor in this position, all the flux established by the stator winding voltage cuts the rotor winding and the voltage induced in the rotor is maximum. For example, with a turns ratio between the stator and rotor of 1:1 and input voltage of 1 volt, ignoring the small transformer losses, the output voltage will be 1 volt.

In figure 5-51C, the rotor is turned so that the two windings are displaced by 30 degrees. Now only a part of the stator flux cuts the rotor winding, and the voltage induced in the rotor is 0.866 volts.

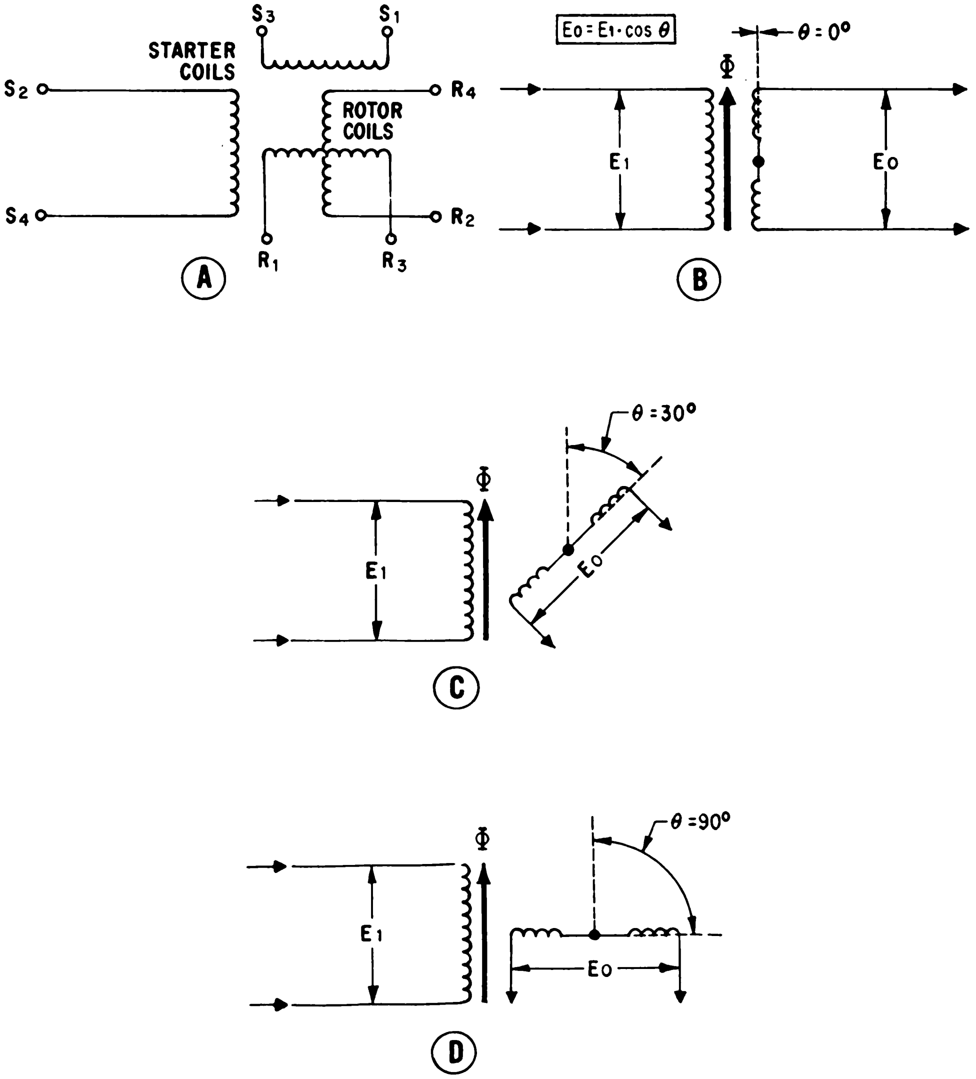
In figure 5-51D, the rotor is turned so that the two windings are displaced by 90 degrees. At this angle there is no magnetic coupling between the windings, and the output voltage is zero.

The output voltage corresponds numerically to the cosine function of the angular displacement between the rotor and stator. This rotor winding is therefore called the cosine winding. With the second rotor winding displaced 90° from the cosine winding, the voltage induced in this winding would correspond to the sine function of the angle of displacement between the rotor and the stator. This naturally would be called the sine winding.

Synchro and Scott-T Transformer Resolver

A standard synchro transmitter and Scott-T transformer combination is used in some resolver applications. For example, the cosine transformer T1 (fig. 5-52A), has a 7.8-to-1 turns ratio. Its primary winding is connected to the S2 winding of the synchro and the center tap of T2. The sine transformer T2 has a 9-to-1 turns ratio. Its primary is connected to S1 and S3 of the synchro.

Figure 5-52B, C and D shows the Scott-T transformer circuit with three angle inputs. In part B of the figure the synchro angle input is zero. The voltages developed by the synchro are +52V at S2, and -26V at S1 and at S3. The potential difference across the primary of T2 is zero. Therefore the output voltage, which is proportional to the sine of the input angle, is zero. There is a 78 V potential difference across the primary of T1, (+58V at S2 and -26V at the center tap of T2). Let's see why there is -26V



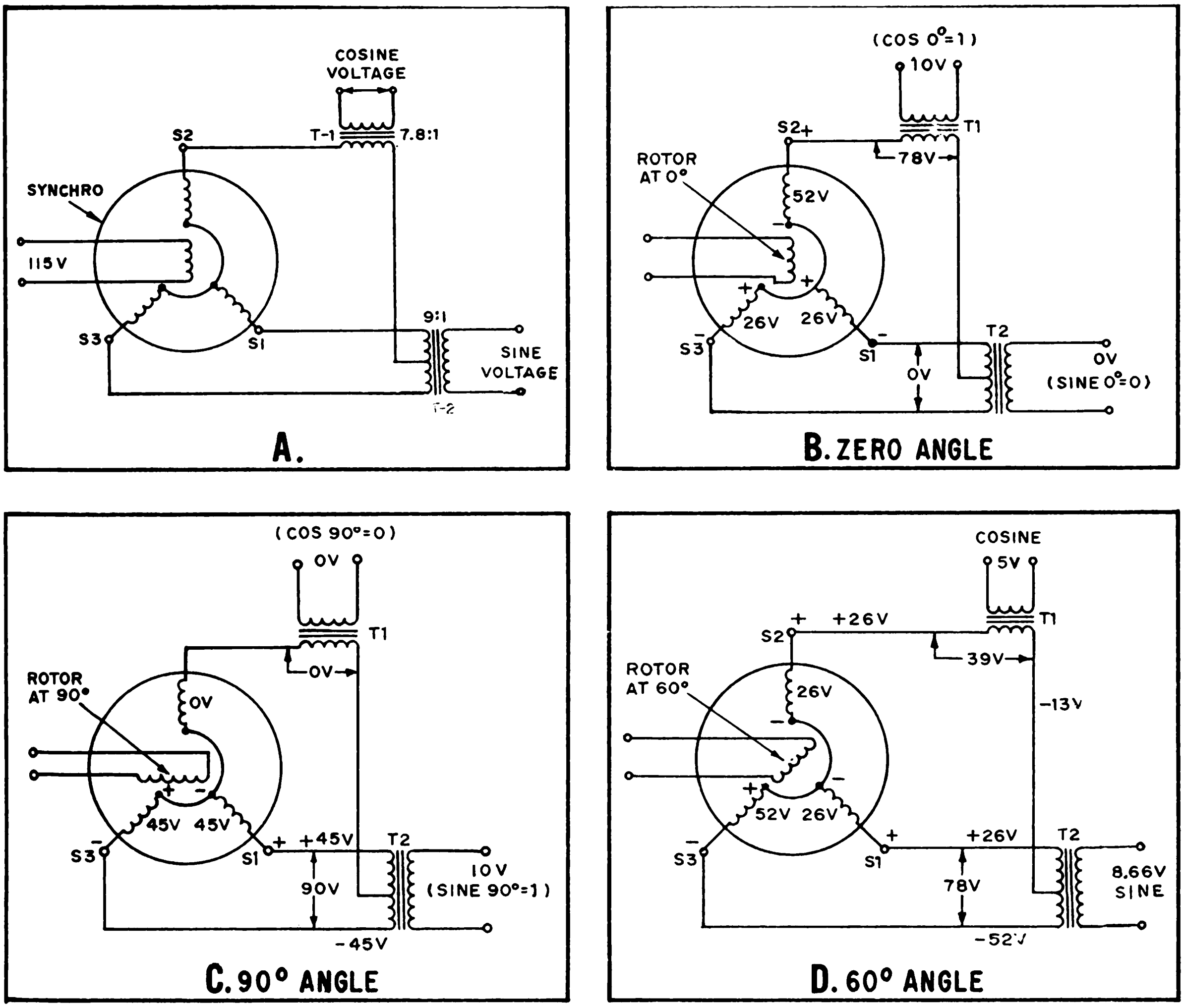
12.10
12.10

Figure 5-51.—Resolver schematic with rotor and stator principle.

at the center tap of T2. With no potential difference across T2, there is no current flow between S1 and S3; hence there is a 26V potential throughout the circuit. Current flow from T2 to T1 will be equal and opposite through the two halves of the primary of T2, and therefore will not affect the sine output voltage of T2.

Since there is a 7.8-to-1 stepdown turn ratio in T1, the output voltage across the secondary winding is 10V, which is the maximum output voltage, and is considered to represent unity. Therefore, with the synchro input voltage representing an angle of zero, the Scott-T transformer set outputs are 10V from T1 and 0 from T2.

In part C of figure 5-52 the synchro voltages +45V at S1, O V at S2, and -45V at S3 represen a 90° angle. There is a 90V potential differenc across the primary winding of T2, (+45V and -45V Since there is a 9-to-1 stepdown turn ratio i T2, the output voltage from the secondary winding is 10V or unity. The potential differenc



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166.40

Figure 5-52.—Synchro and Scott-T transformer resolver.

across the primary winding of T1 is zero, and its output is zero. The center tap of T2 is at the midpoint between +45V and -45V, hence it is at zero volts. Therefore, with the synchro voltages representing a 90° angle, the Scott-T transformer set output voltages are OV from T1, and 10V from T2.

In part D of figure 5-52 the synchro voltages, +26V at S1 and S2 and -52V at S3, represent a 60° angle. The potential difference across the primary winding of T2 is 78V, (+26V), and -52V). With the 9-to-1 ratio, the output from T2 is 8.66V. The potential difference across the primary winding of T1 is 39V, (+26V and -13V) With the 7.8-to-1 ratio the output voltage from T1 is 5V. (Since there is 78V across the primary of T2, 39V is dropped across each half of the winding. Hence the potential at the midpoint of the winding is (-52 minus 39 or -13V). Therefore, with synchro input voltages representing an angle of 60° the output voltages are 8.66V from the sine transformer T2, and 5V from the cosine transformer T1.

If you tabulate the output voltages for the three angle inputs, you will find they are proportional to the sine and cosine functions of the angles. The Scott-T transformer set gives the sine and cosine of other synchro input angles in the same manner as for the angles shown. When the sine or cosine becomes negative, the change in algebraic sign is indicated by a reversal in the phase of the output voltages.

POTENTIOMETERS

In fire control instruments the value of a quantity can be represented by the position of a shaft. Frequently, however, an instrument may require this information in an electrical form. A potentiometer is one the simplest means of converting mechanical positional information to a proportional voltage.

Basically, a potentiometer solves a percentage problem. The electrical input, which may be either an a.c. or a d.c. voltage, is applied across the winding of the potentionmeter (fig. 5-53). Unity in the percentage problem is represented by the instantaneous value of the input voltage and by the total resistance of the winding. The wiper arm or sliding contact is moved by the mechanical input along the winding to "pick up" a percentage of the input voltage. Ohm's law, E = IR, tells us that the voltage and the resistance in a circuit are directly related. We will discuss the current in the circuit later. In the diagram the wiper is positioned half-way down the potentiometer winding, the input voltage is 10 volts; the output from the wiper is 5 volts, or 50% of the input voltage and of the total resistance of the winding.

A potentionmeter is a variable voltage divider, with an output voltage that is a percentage of the input voltage. The amount of output voltage i proportional to the position of the wiper. Thu a potentiometer is a voltage control devic

A rheostat is a current control device th functions similarly to a potentiometer. In circuit (fig. 5-54), only two leads are connecte to the rheostat. When we move the wiper we ar varying the amount of resistance in series wi the load. Hence we are varying the current flo through the load by putting more or less resistanc in series with it. Note that none of the rheostat' resistance is in parallel with the load. As a curre control device, a rheostat will determine th amount of power applied to the load.

Potentiometer Construction

Most of the potentiometers in fire contr equipment are wire wound. The resistance wire wound around a form called a card or mandre The wiper arm glides along the resistance wir making contact with it to complete the outpu circuit. The movement of the wiper from one tur to the next will add resistance between the wip and one end of the winding, while simultaneous removing an equal amount of resistance fro between the other end and the wiper. Since t voltage drops along the winding are proportion to the resistance, the voltage picked off by t wiper increases from zero at one end of the winding to maximum value at the other end.

In most of the potentiometers you will work o the motion of the wiper arm is rotary and th card has a cylindrical shape. There are single turn potentiometers, in which the wiper is limite to one revolution or less, and multiturn potentiometers, in which the wiper can make ma revolutions.

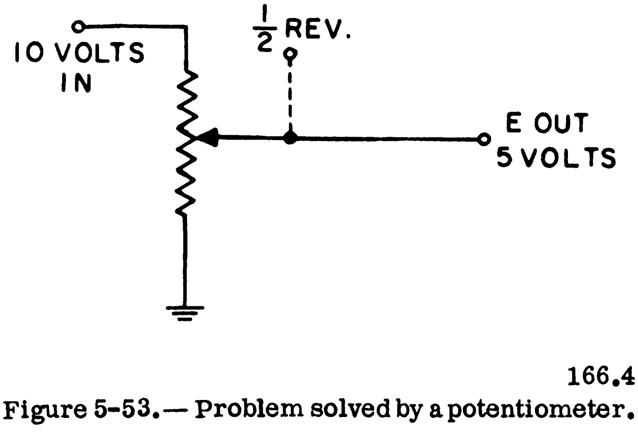

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Figure 5-53.— Problem solved by a potentiometer.

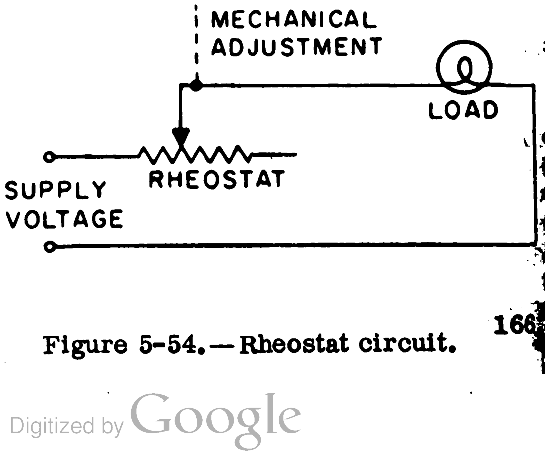

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Figure 5-54.—Rheostat circuit.

The wiper arm in some potentiometers moves a translatory manner (back and forth in linear otion). This type has limited application in the issile field. Functionally, however, its operation the same as potentiometers with rotary wiper otion.

ypes of Potentiometers

LINEAR POTENTIOMETERS.—A linear po- ntiometer's resistance wire is evenly wound and s card is of uniform width throughout. Thus the put voltage is distributed equally across each rn of the resistance wire and evenly along the inding. Therefore, a movement of the wiper from ne turn to the next will add equal amounts of esistance. And it follows that the output voltage ill vary linearly with the movement of the input haft. In other words, for the same amount of haft rotation equal changes in the output voltage ill be obtained.

NONLINEAR POTENTIOMETERS.—A non- ear potentiometer is one whose voltage output proportional to a nonlinear function of the input haft's rotation. The resistance wire is wound on pecially shaped cards so that each turn has a ifferent length of wire, thus the total resistance s distributed unevenly along the length of the inding. Therefore, the voltage output will vary n a nonlinear fashion as the wiper is moved rom one turn to another. Cards can be shaped o produce an output voltage proportional to many unctions, such as sine and cosine.

Nonlinear potentiometers are sometimes re- erred to as computing, shaped, or tapered. We will over nonlinear potentiometers in greater detail n the chapter on analog computers.

otentiometer Characteristics

LINEARITY.—A potentiometer does have a mall amount of deviation from the correct rela- ionship between the input shaft rotation and the oltage output. This deviation is generally ex- ressed in percentage of the total voltage and is sually shown on the housing of the potentiometer. n figure 5-55, a linear potentiometer's output oltage curve varies from a straight line. (In eneral, linearity is a straight line relationship etween quantities.) The deviation never exceeds 0.01 volts. From the formula shown in the figure, we can determine that with a supply voltage of 10 volts, the linearity of the potentiometer is 0.1 percent.

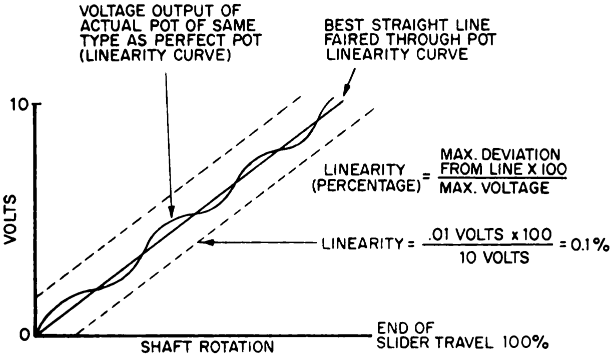

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Figure 5-55.—Zero base linearity curve.

There are many factors which will cause a potentiometer's output to deviate from the designed value. Some of these factors are:

1. Fluctuations in the supply voltage.
2. Unwanted eccentricity of the wiper arm motion.
3. Imperfections in the resistance material.
4. Noise in the potentiometer.
5. Potentiometer resolution.
6. Loading of the potentiometer.

RESOLUTION.—The resolution of a potentiometer is determined by the way its resistance element is constructed. Most resistance elements are composed of coiled resistance wire. As the wiper is moved across these coils, the resistance tapped off will vary in small steps, called increments (fig. 5-56). Resolution is the term

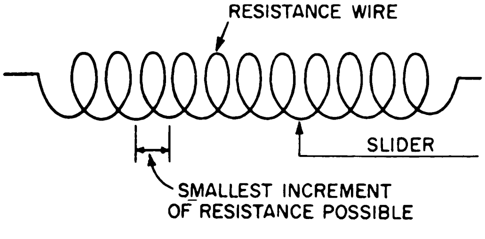

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Figure 5-56.—Reason for pot resolution.

used to describe the smallest increment of resistance as the wiper moves from turn to turn.

An increment is the amount of resistance of one coil of wire. The size of these increments with respect to the total resistance determines the resolution of the potentiometer. Thus, resolution equals the smallest increment (I) possible divided by total potentiometer resistance (Rt). The formula for percent of resolution would equal:

$$\text{Resolution (percent)} = \frac{I \times 100}{Rt}.$$

It should be apparent to you that resolution of a potentiometer is of importance in a fire control system. Potentiometer resolution is a system design function and accordingly, a potentiometer should NOT be replaced by a substitute potentiometer with a different resolution.

LOADING EFFECT.—Since the load is in parallel with some of the resistance of the potentiometer it will draw some current. But the output current is held to a minimum by feeding the output into a load whose resistance is high compared to the potentiometers' resistance.

The graphs in figure 5-57 illustrate the loading effect on a linear potentiometer. Part A shows that with a high resistance load the loading effect is negligible. But, if the load has a low resistance as shown in part B of the figure, then the loading effect is great and the output voltage will change considerably.

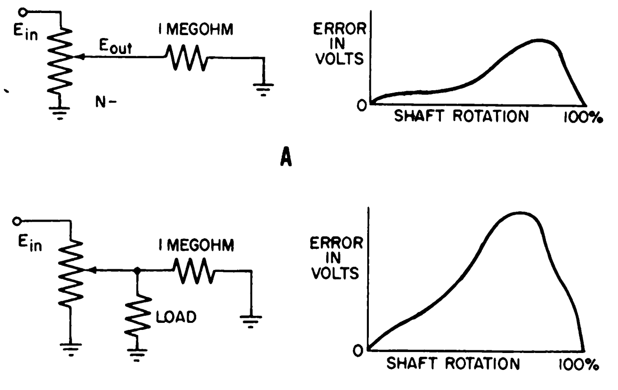

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Figure 5-57.—Loading effect on single-input pot.

NOISE.—Noise is a fluctuating distortio the potentiometer's output, (fig. 5-58). N may be caused by several factors. Vol variations may be caused by resistance cha between the wiper and the resistance eleme The tension of the wiper may vary, or for matter between the wiper and the resista element may cause unwanted resistance chan in the potentiometer. In wire-wound poten meters, noise is generated because of the s action as the wiper moves from one coil another.

TACHOMETER GENERATORS

A tachometer generator, commonly cal "tach" for short, produces a voltage whose m nitude is proportional to the number of revo tions its rotor makes per unit of time. The ph or polarity of the output voltage is determined the direction the rotor is turned. Hence a tac output voltage is representative of the speed the direction of the rotor's motion.

The tach's rotor is mechanically coupled to drive shaft of the unit whose velocity we wish measure. Thus its output voltage is an ana representation of the unit's velocity or rate motion.

Tachometer generators are sometimes ferred to as rate generators.

A.c. Tachometer Generators

The drag-cup tachometer generator (fig. 5-5 shows the construction and operating princip

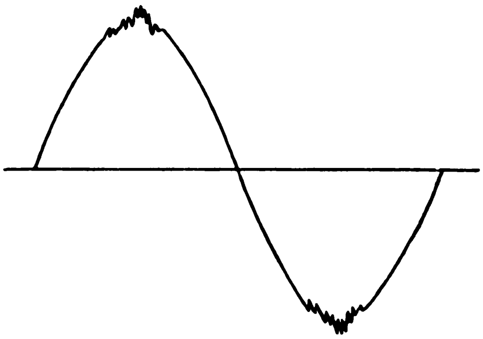

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Figure 5-58.—Pot noise as seen on an oscil scope.

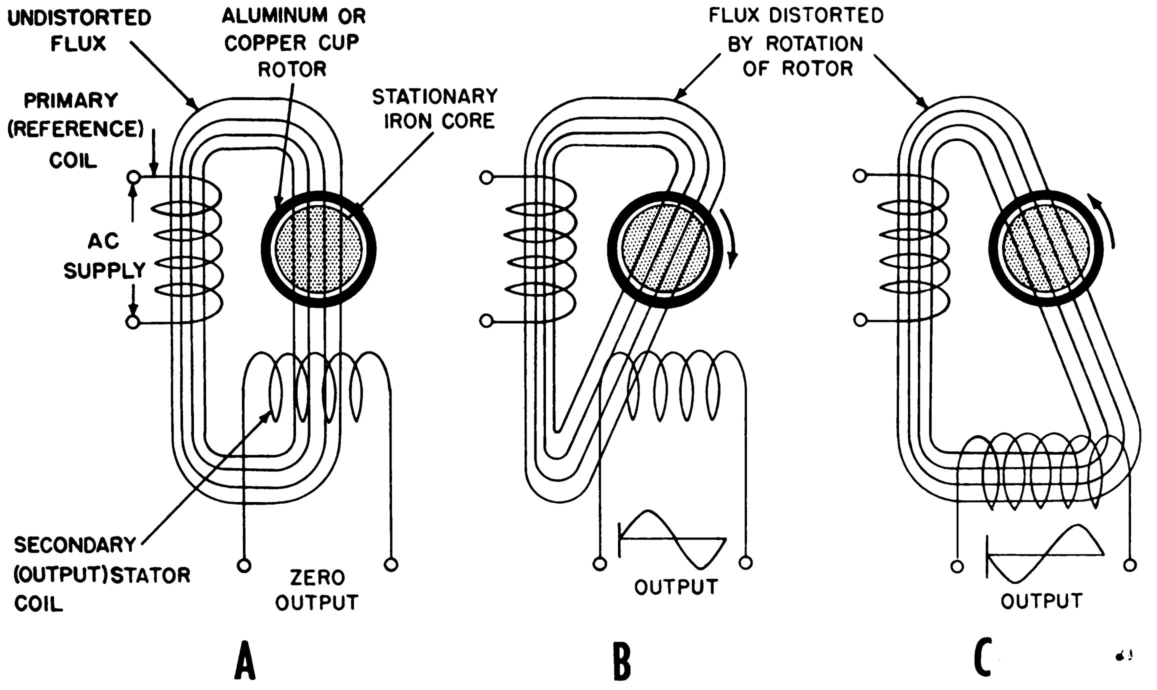

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Figure 5-59.—A.c. drag-cup rate generator: A. Rotor stationary; B. Rotor turning clockwise; C. Rotor turning counterclockwise.

of the a.c. drag-cup generator. The tach has two stator winding 90 degrees apart, and an aluminum or copper cup rotor. The rotor rotates around a stationary soft-iron magnetic core. One stator winding, is energized by a reference a.c. source. The other stator winding is the tach's output or secondary winding.

The tach's operation is based on transformer principles. The voltage applied to the primary winding creates a magnetic field. If the drag-cup rotor is stationary, the magnetic field is at right angles to the secondary winding (fig. 5-59A). When the rotor of the tach is turned, it distorts the magnetic field so that it is no longer 90 electrical degrees from the secondary winding. Flux linkage is created with the secondary winding and a voltage is induced (fig. 5-59B and C). The amount the magnetic field will be disturbed is determined by the angular velocity of the rotor. Therefore, the magnitude of the voltage induced in the secondary winding is proportional to the rotor's velocity.

The direction of the magnetic field's distortion is determined by the direction of the rotor's motion. If the rotor is turned in one direction the lines of flux will cut the secondary winding in one direction. If the motion of the rotor is reversed the lines of flux will cut the secondary winding in the opposite direction. Therefore, the phase of the voltage induced in the secondary winding measured with respect to the phase of the supply voltage is determined by the direction of the rotor's motion.

The frequency of the tach's output voltage is the same as the frequency of the reference voltage. This is reasonable since the magnetic field produced by the primary winding fluctuates at the supply's frequency. The output voltage is generated by the alternating flux field cutting the secondary winding; therefore, the output voltage must have the same frequency as the supply voltage.

Another type of a-c tach has a squirrel-cage rotor. Otherwise its construction and principles of operation are identical to the drag-cup tach. You studied generators with squirrel-cage rotors in the Basic Electricity course, NavPers 10086-B.

D. c. Tachometer Generators

The d.c. tachometer generator employs the same principles of magnetic coupling between the reference winding and the output winding as the a-c tach. However, the d.c. tach has a stationary primary magnetic field. This magnetic field is frequently supplied by permanent magnets built into the tach. The amount of voltage induced in the rotor winding is proportional to the magnetic flux lines the winding cuts. The polarity of the output voltage is determined by the direction in which the rotor cuts the lines of magnetic flux.

ELECTRICAL COMPONENTS

FUSES

The simplest and most common protective device is a fuse. Functionally, a fuse consists of a metal alloy strip or wire, and terminals for electrically connecting the fuse into the circuit. Most fuses are made of an alloy of tin and bismuth; but copper, aluminum, German silver, or iron alloys also have been used. All fuses are rated by the amount of current that is safely carried by the fuse element, and by voltage. Usually, the current rating is in amperes, but some fuses are rated in fractions of an ampere.

The fuse element is designed to melt when the current through it exceeds its rated value. Thus, when the circuit is overloaded, the fuse element melts and opens the circuit that it is protecting. However, all fuse openings are not the result of overloads. Aging of the fuse element, poor contact at the fuse holder, and the condition of the surrounding atmosphere will affect the time required for the element to melt. A fuse is always placed in series with a circuit so that it opens the circuit automatically, if excessive current is drawn.

Delayed-Action or Time-Delay Fuses

Some equipment, such as electric motors, requires more current to start than for normal running. Thus, a fuse rating that will give running protection might blow during the period when high current is required. Delayed-action fuses have been developed to handle these situations.

A heater element is connected in parall with the fuse element in order to get the d layed action. During normal operation the he developed in the fuse link is not great enoug to melt the link. The melting, or opening, the fuse link depends on the transfer of heat the link from the heater. Therefore, more tim is needed to melt the link than would be required if the link were directly heated.

Because the heater and fuse element are parallel, the opening of the fuse element wil cause the total circuit current to flow throug the heater. The high current will cause th heater to burn out and completely open th circuit.

Another type of delayed-action fuse has th fuse element and heater connected in serie Current above that of the rated value for short time will not open the fuse or heate However, prolonged overloads cause the heate section to become hot enough to melt the junctio between the elements and open the circui

Delayed-action fuses are sometimes calle "slow-blow" fuses, and two trade names, Fusestat and Fusetron, are in common use.

Cartridge Fuses

Cartridge fuses are made in various physic sizes. The more common types of these fuses a their holders are shown in figure 5-60. The curren capacity of each fuse is marked on the side o one of the ferrules (end caps). The size i indicated by the AG or AB number. The A

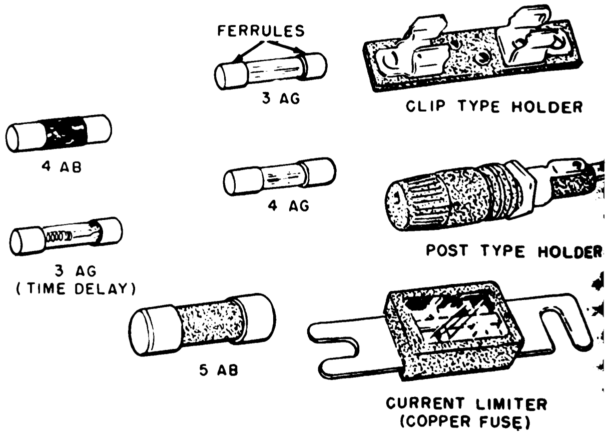

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Figure 5-60.—Cartridge fuses and fuse holder

dicates a glass body and the AB a bakelite dy. Listed below are the dimensions of the andard AG and AB numbers.

1 AG or 1 AB is 5/8 in. long and 1/4 in. diameter.
3 AG or 3 AB is 1 1/4 in. long and 1/4 in. in ameter.
4 AG or 4 AB is 1 1/4 in. long and 9/32 in. diameter.
5 AG or 5 AB is 1 1/2 in. long and 13/32 in diameter.

These fuses are rated at 80 percent of the irrent that they will carry indefinitely. The ISTANTANEOUS fuse must be able to carry current 10 percent greater and must open e circuit at a current 25 percent greater than e fuse rating.

urrent Limiters

Devices somewhat similar to fuses, called irrent limiters, are used in circuits that carry gh currents. (See fig. 5-60.) The current miter consists of a copper link of carefully redetermined sections. The sections melt when normally high currents start to flow. The elting sections have a high arc resistance to ep the circuit current within the capacity of e limiter. If the excessive current is only temporary surge, the melting ceases and the rcuit continues to operate as if no abnormal irrent had been present. Repeated applications excessive current, or uninterrupted application r a period of several seconds, melt through e sections and cause the limiter to function the same manner as a fuse.

use Holders

The most common class of fuse holders ed in Navy test equipment is the post type lder shown in figure 5-60. It may be a screw-in a bayonet type, both of which are securely ounted to the chassis or front panel of the uipment. The purpose of the holder is the ime, regardless of type—to hold the fuse se- irely with good electrical connect and phys- al stability for protection from mechanical bration and electrical short circuit.

Care should be used to ensure that the fuse of a physical size compartible with the holder. uses which are undersized allow physical ovement and arcing, resulting in a blown fuse, ratic operation, or a damaged holder; fuses which are too large may cause cracking or breaking of the holder. Force should never be applied to either the fuse or the holder, since most are fragile devices.

Post type fuse holders are normally series-connected in the line, with the end connection to the power source and the center connection to the load. When connected in this fashion, the equipment is protected in the event of a broken holder—a short circuit from fuse holder to chassis ground will result in a blown fuse and excessive current will not flow. Reversed connections will not furnish this protection. Connection is normally made by solder connections, although some fuse holders are connected by use of the screw and lug method.

The type EL-1 fuse holder consists of a base and a plug, as shown in figure 5-61. The base extends behind the panel, and into it is screwed the plug containing the fuse. Behind a hole in the plug cap is a small neon lamp used as a blown-fuse indicator, which lights when the energized circuit through the holder is interrupted by the blowing of a fuse. Series resistors of different

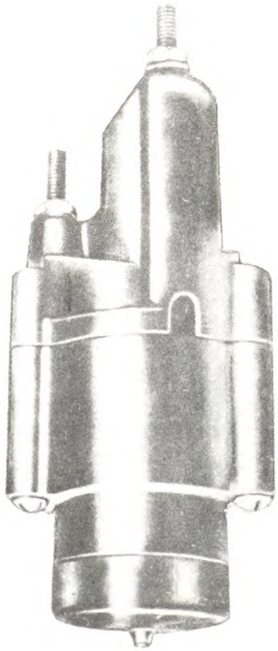

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Figure 5-61.—Fuse holder, type EL-1.

values are used with the lamp on 125- and 250-volt circuits, except for the MIDGET holder, which is rated for 125 volts only.

The types FHL10G, FHL11G, and FHL12G (fig. 5-62) consist of fuse holder body and a fuse carrier. The body is mounted on the panel, and the carrier with the fuse placed in the clips is inserted into the body in a manner similar to inserting a bayonet type lamp into a socket. Removal of the fuse is accomplished by pushing and turning the fuse carrier in a counterclockwise direction, again similar to the removal of a bayonet base lamp. The types FHL10G and FHL11G accomodate 1 1/4" x 1/4" diameter fuses. The type FHL10G will hold two fuses and can therefore be used to fuse both sides of the line, or, in conjunction with a type FHL11G, will fuse a three phase line. Type FHL12G will accommodate 1 1/2" x 13/32" diamter fuses.

The extensive use of low-voltage power supplies has required the use of incandescent lamps in place of neon glow lamps in some indicator light circuits. A modification of the type FHL10G fuse holder has recently been designed, which provides a third terminal connected to a 28-volt incandescent lamp in the cap. By insertion of a suitable resistor between the load terminal and the added terminal, the lamp will be energized by a sufficient voltage to become visible when the fuse has blown, In some low-voltage fuse holders the resistor and lamp are included within the clear plastic cap. Low-voltage fuse holders should not be used in sensitive, low-current equipment. Where an overload condition occurs and the fuse blows, the low resistance indicator circuit may pass sufficient current to damage the equipment.

Due to the design of certain fuses and in cases where space does not permit use of indicator type fuse holders, separate indicator light circuits are mounted on a panel and connected in parallel with separately mounted fuses and fuse clips. In some cases an alarm circuit in the form of a bell or buzzer is used in place of the indicator light.

Blown-Fuze Indicators

It is not always possible to detect a blown fuse by a visual examination. Hence, fuses are often equipped with a device that will provide a visual indication so that a blown-fuse condition can be readily detected (fig. 5-63). These devices consist of the spring-loaded and the neon-lamp types of blown-fuse indicators.

In the spring-loaded type (fig. 5-63A), when the link opens, it releases a spring that is held under tension. This action exposes an indicator, which makes the visual location of the blown fuse possible.

The neon-lamp type (fig. 5-63B) is designed to be mounted on the fuse. When the link opens, a neon lamp glows to show a blown fuse.

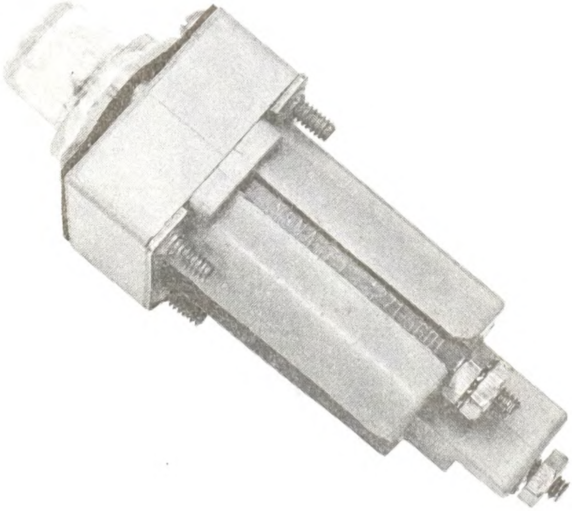
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Figure 5-62.—Fuse holder, type FHL 12G.

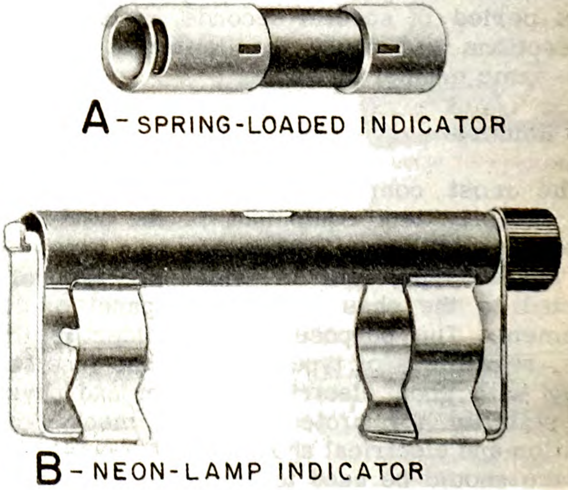

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Figure 5-63.—Blown-fuse indicators.

BLING

pes of Cables

The various electronic systems aboard ship pend on power supplied by the ship's service nerators. This power is distributed to the ctronics spaces by a system of cables. Power bles are normally installed by shipyard forces, t the FT should know in detail the location d characteristics of the cabling that supplies e equipment with which he works.

You should become familiar with the current-rrying capacity of cables; their insulation rength; and their ability to withstand heat, ld, dryness, bending, crushing, vibration, twist- g, and shock. Several types of cables are used the applications under discussion, with design aracteristics suited to their location and pur- se.

Type SGA (Shipboard, General use, Armored) bles are designed to have a minimum diameter d weight consistent with service requirements fixed wireways on combatant naval vessels. his type supersedes the older, widely used pe HFA (Heat and Flame resistant, Armored) ble.

Type SSGA cable (fig. 5-64) consists of randed copper conductors (in this case, only e conductor—indicated by the "S" before SGA) sulated with silicone rubber and glass fibers ound which is placed an impervious sheath. he sheath is covered with braided metal armor, d then a coat of paint is applied.

The SGA cables are designed as follows:) SSGA, single conductor; (2) DSGA, twin ouble) conductor; (3) TSGA, three conductor; d (4) FSGA, four conductor.

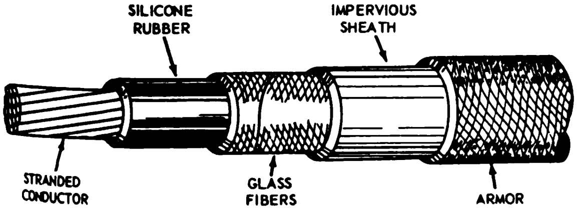

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Figure 5-64.—SSGA cable.

The HFA cables (also composed of stranded copper conductors) are designated as follows: (1) SHFA, single conductor; (2) DHFA, twin (double) conductor; (3) THFA, three conductor; (4) FHFA, four conductor; and (5) MHFA, multiconductor.

Twisted-pair telephone cables are designated as TTHFWA.

Many applications aboard ship require cables that can be bent and twisted again and again without damaging the conductor insulation or the protective covering. For such applications, flexible cables are used.

Flexible cables have synthetic rubber or synthetic resin insulation and a flexible sheath that is resistant to water, oil, heat and flame. However, these cables are not as heat and flame resistant as armored HFA and SGA cables. Flexible cables for general use are designated by the letters HOF—For example, DHOF, THOF, and FHOF. Flexible cables for limited use are designated by the letters COP—for example, DCOP, TCOP, and FCOP.

Other types of cables used in electronics work are:

1. DRHLA—Double conductor, radio, high-tension, lead armored.
2. FHFTA—Four conductor, heat and flame resistant thin-walled armor.
3. MCSP—Multiple conductor, shielded pressure resistant (submarine applications).
4. TTRSA—Twisted-pair telephone, radio shielded, armored (characteristic impedance approximately 76 ohms).

Designation of Conductor Size

Generally, when the size of the individual conductors contained in the cable is indicated in the cable designation, the numeral (or numerals) following the letter designation indicate the approximate cross-sectional area of the individual conductors in thousands of circular mils to the nearest thousand. For example, TSGA-60 is a 3-conductor armored cable for general shipboard use, with each conductor having a cross-sectional area of 60,090 circular mils. However, when the numerals immediately following the letter designation indicate the number of conductors comprising the cable, the size of the individual conductors may be indicated by additional numerals enclosed in parenthesis. For example, MDGA-19(6) is a 19-conductor electrical power cable for shipboard nonflexing service, with each conductor having a cross-sectional area of 6,512 circular mils.

Multiple-Conductor Cable Designations

Multiple-conductor cable types and class designations are followed by a number that indicates the number of conductors. For example, MSCA-30 is a heat and flame resistant armored cable with 30 conductors.

For telephone cable, the number indicates twisted pairs. For example, TTHFWA-25 means that the cable contains 25 twisted pairs; TTRSA-4 means that the cable contains 4 pair individually shielded.

Selection and Installation of Cables

You should have some knowledge of the power cables feeding fire control equipment. There are at least five items that must be considered when power cables are installed They are (1) the maximum connected load in amperes, (2) the possible added load due to future installations, (3) the demand factor (that is, the average demand in amperes over a 15-minute interval divided by the total connected load in amperes), (4) the cable service rating (the physical characteristics required for a given type of service), and (5) the maximum allowable voltage drop in the part of the circuit under consideration.

The current-carrying capacity and voltage-drop limitations determine the cable size for a particular application. The current capacity is dependent upon the type and size of the conductor, the permissible temperature rise, and the physical characteristics of the space in which the cable is installed. The allowable voltage drop depends on the type of load connected to the circuit.

All connections to cables are made in standard appliances and fittings; splice connections are not made. However, cable splices are permitted as an emergency repair (by ship's force), and on a limited basis (by repair activities) where it has been determined that time and replacement cost is excessive, and existing cable is in good condition. Cables entering watertight equipment are brought into the equipment through stuffing tubes (stuffing tubes and kickpipes are discussed later). Where cables pass through decks and watertight bulkheads, stuffing tubes are used. Cables passing through decks are protected from mechanical injury by kickpipes or riser boxes.

Cable Tags

All ship's cables are identified by met tags. For example, electronic cable desig tion 2R-FB7 (fig. 5-65) will illustrate the metho of marking the cables between units of equip ment. The 2R-FB indicates the second guid missile fire control radar on the ship; R i dicates electronics, FB indicates a guided missi radar circuit. The 7 indicates cable number of the guided missile radar.

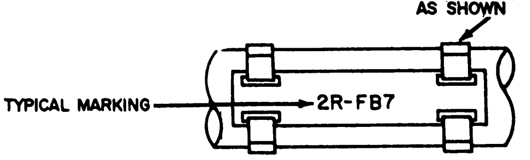
CONNECTORS

In the discussion which follows, the wor "connector" is used in a general sense. It ap plies equally well to connectors designated "AN" numbers and those designated by "MS numbers. AN numbers were formerly used fo all supply items cataloged jointly by the Arm and Navy. Many items, especially those of old design, continue to carry the AN designato even though the supply system is shifting ov to MS (Military Specification) numbers.

Connector Construction

Electrical connectors are designed to pro vide a detachable means of coupling betwe major components of electrical and electron equipment.

These connectors vary widely in design an application. Each connector consists of a plu assembly and a receptacle assembly. The tw assemblies are coupled by means of a couplin nut, and each consists of an aluminum she containing an insulating insert which holds th current-carrying contacts. The plug is usuall attached to a cable end and is the part of th connector on which the coupling nut is mounte The receptacle is the half of the connector t which the plug is connected and is usuall mounted on a part of the equipment.



12.74

Figure 5-65.—Typical cable tag.

There are wide variations in shell type, de-ign, size, layout of contacts, and style of insert. ix types of connector shells are shown in igure 5-66.

Connectors MS 3100 is a wall-mounting re-eptacle. It is intended for use with conduit to liminate the necessity of installing conduit oxes.

Connector MS 3101 is a cable-connecting eceptacle, and is used with cable or in other nstallations where mounting provisions are not equired.

MS 3102 is a box-mounting receptacle, and s intended for use where a detachable con-nection is required on a shielded box or unit f equipment.

MS 3106 is a straight plug which is used when ircuits are to be connected where space limita-ons are not critical. It consists of a front hell (usually referred to as an "insert barrel"), coupling ring, the insert, an insert retaining evice, and a rear shell.

MS 3107, a quick-disconnect plug, is used here very rapid disconnections must be made. special coupling device is used instead of a oupling ring; otherwise it is similar to MS3106.

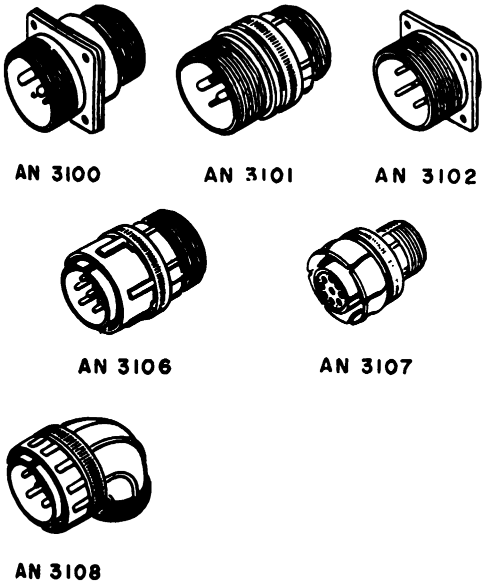


Figure 5-66.—Connector shells. 12.76

MS 3108, a 90° angle plug, is similar in construction to MS 3106 except that the rear shell provides a right angle bend which is required where space is limited.

The shells of MS connectors are made in eight types, each for a particular kind of application. A letter designation is used in the MS number to indicate the shell design, as in MS 3106E, where E is the shell type indicator. The shell indicators are as follows:

A—Solid shell.
B—Split shell.
C—Pressurized type.
D—Sealed construction.
E—Environment resistant.
F—Vibration resistant.
H—Flame barrier shell.
K—Fireproof construction.

Solid shell connectors are used where no special requirements, such as fireproofing or moistureproofing, must be met. The rear shells are made from a single piece of aluminum.

Split shell connectors allow maximum accessibility to soldered connections. The rear shell is made in two halves, either of which may be removed. Figure 5-67 shows an exploded view of one type of a split-shell connector.

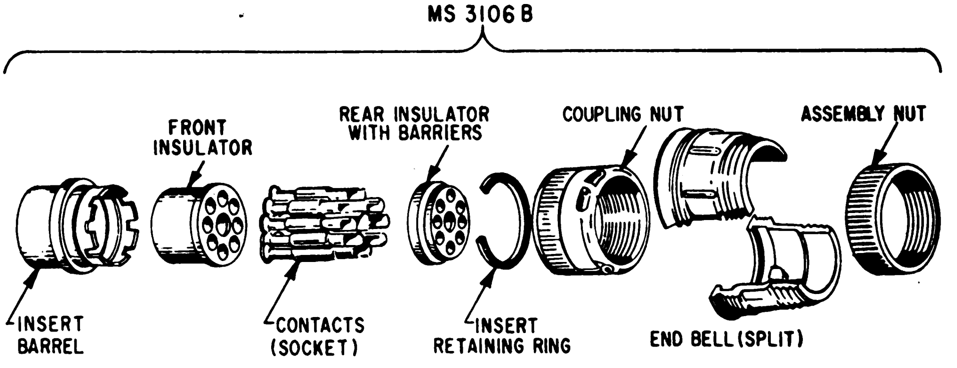
Pressurized connectors provide a pressure-tight feed-through for wires that pass through walls or bulkheads of pressurized compartments.

The contacts are usually molded into the insulator, and the shell is spun over the assembly to seal the bond.

Sealed connectors are employed in equipment that is sealed and operated under gas pressure. These connectors include a glass-to metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration-resistant connectors are designed for use in equipment that is subjected to intense vibrations in installations on or near reciprocating engines.

Fireproof connectors are made under specifications which require that the connector maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a ceramic material, and special crimp type contacts are used.



AE.59

Figure 5-67.—Exploded view of a split-shell connector.

Moisture-resistant connectors consist of a combination of the features of the solid shell, the pressurized, and the vibration-resistant types. The component parts of this kind of connector are shown in figure 5-68.

As pointed out previously, there is a MS numbering system for identifying the connectors. For example, a connector may be identified as consisting of a MS 3106B-22-12S plug with a MS 3102-22-12P receptacle. These identifying letters and numbers stand for the following:

MS	MS nomenclature system
3106	Specification number for plug (straight plug)
3102	Specification number for receptacle (box receptacle)
B	Shell design (split type)
22	Size of the shell
12	Insert arrangement
P	Pin contacts
S	Socket contacts

Occasionally it may be necessary for you to fabricate a cable using MS connectors. The type of connector to be used will be specified in the maintenance manual for the particular equipment.

COAXIAL CABLES AND CONNECTORS

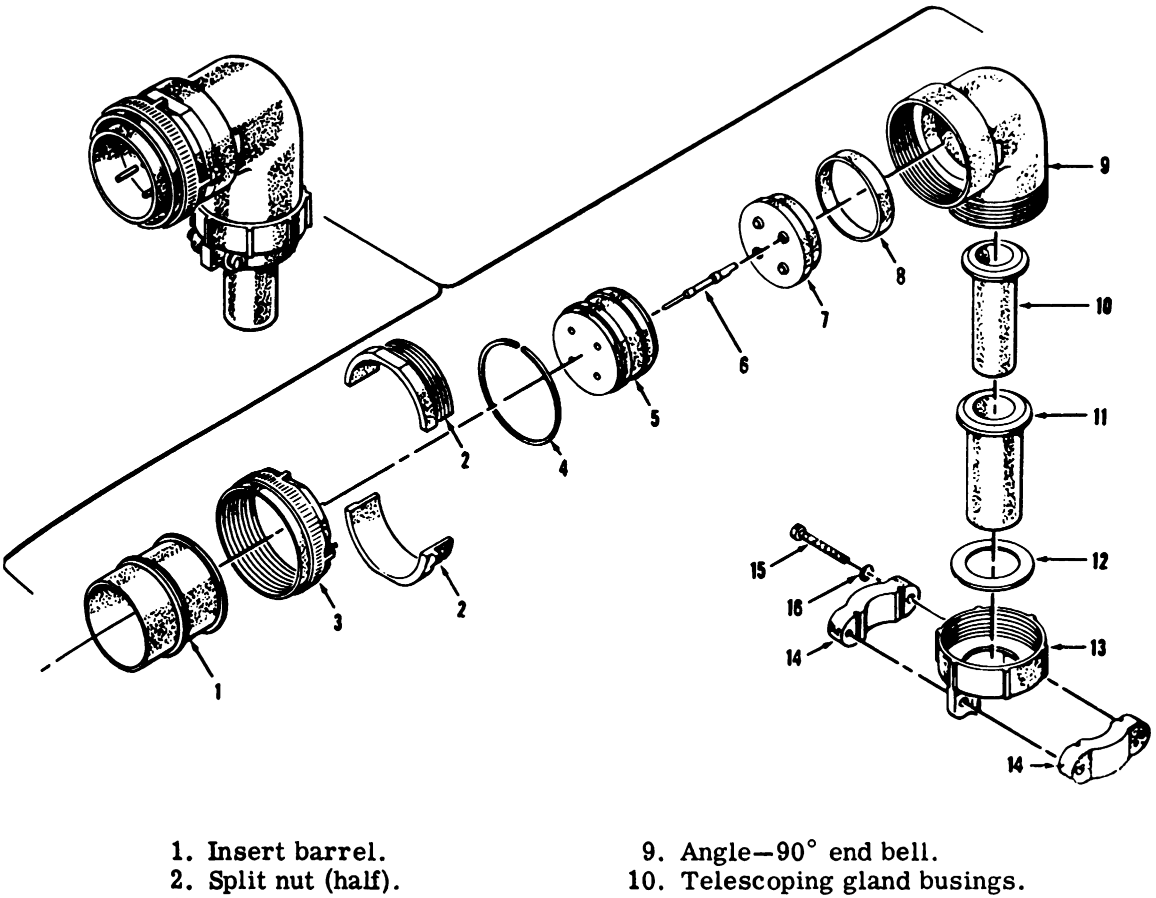
Flexible coaxial cables (sometimes called RF cables) are a special type of cable used for carrying video and RF signals, cathode-ray-tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals o radar receivers, transmitters,and indicators These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are of importance in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies, and are used at frequencies as high as 3,000 MHz.

The name coaxial is derived from the construction, in that the inner and outer conductors have a common axis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper, either plain, tinned, or silver coated. The dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of either plain, tinned, or silver coated copper. The outer covering is made o a synthetic resin (vinyl), teflon tape, or chloroprene. This covering serves both as weatherproofing and protection from mechanical abuse

Flexible coaxial cables are classified in four groups; namely, general purpose, high temperature, pulse, and special characteristics The general purpose cables consist of various sizes of cables as just described. The high temperature cables are basically the same but usually have a dielectric made of teflon, and the outer covering is made of teflon tape and fiber glass braid which enables it to withstand h temperatures. Pulse cables have the ability withstand high voltages because of conductor cing and the type of dielectric used in their nstruction. Figure 5-69 and 5-70 illustrate four groups of flexible coaxial cables.

The special characteristics cables are made various materials and sizes of inner con- tor, outer conductor, dielectric, and outer ering. By varying these parts the capaci- ce, impedance, shielding, attenuation, voltage ing, and the ability to withstand weather l abuse are varied to fit special requirements. th exception of the special characteristics type, these coaxial cables have an impedance in the order of 50 to 75 ohms. The impedance of the special characteristics type is often much higher. An example is the RG-65A/U which has an approximate impedance of 950 ohms and is used as a high impedance VIDEO cable. In replacing a coaxial cable, care should be exercised to use the correct replacement. Otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3,000 MHz flexible coaxial cables have appreciable losses. At these frequencies rigid coaxial cables are used with air

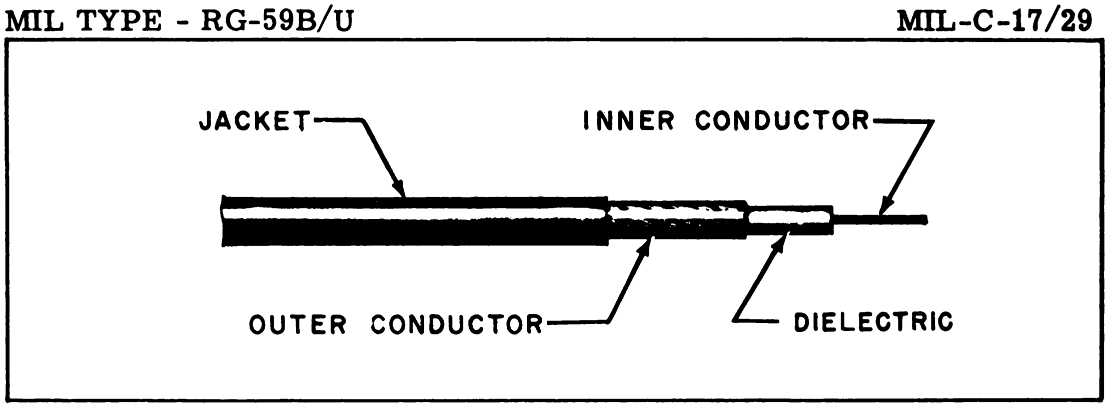


1. Insert barrel.
2. Split nut (half).
3. Coupling nut.
4. Split-nut retaining ring.
5. Insulator.
6. Contact (pin).
7. Grommet.
8. Ferrule.
9. Angle—90° end bell.
10. Telescoping gland busings.
11. Telescoping gland busings.
12. Bushing washers.
13. Gland-clamp fittings.
14. Clamp saddles.
15. Clamp-saddle screws.
16. Lockwashers.

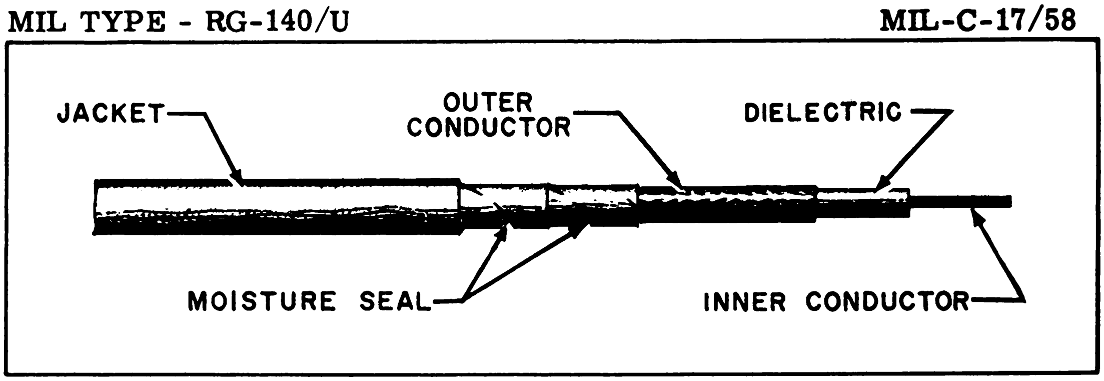
AE.60

Figure 5-68.—Exploded view of a 90° angle connector.

GENERAL PURPOSE CABLES



HIGH TEMPERATURE CABLES



167.744

Figure 5-69.—General and high temperature coaxial cables.

as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

Coaxial connectors are divided into series and are shown in figure 5-71. Each series consists of plugs, panel jacks, receptacles, and straight and right angle adapters.

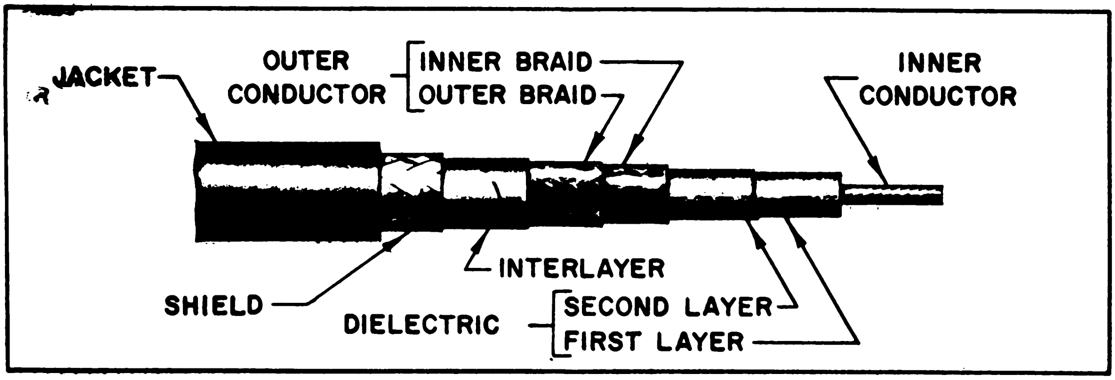
Series UHF connectors are low-cost, general purpose connectors of nonconstant impedance. The small and large coaxial types are for use with small and medium size coaxial cables in applications where line imbalance or increased standing wave ratio is not important. Where impedance matching is necessary, C, N, or BNC series connectors are used. Both small and large series UHF connectors can be weatherproofed for outdoor use but most are non weatherproof.

The twin connectors are similar to the seri UHF connectors except for the fact that th have twin center conductors and are to used with small and medium sized twin-conduct cables. Twin connectors are available in sma weatherproof and nonweatherproof types and la nonweatherproof types.

Series N connectors are the most popu constant impedance connectors for medium s coaxial cables. They can be used up thro microwave frequencies with minimum line i balance or increase in standing-wave rat

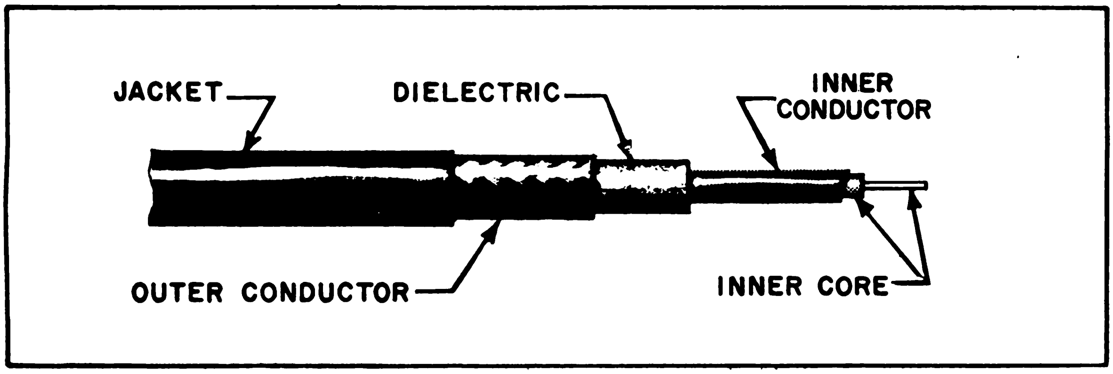
PULSE CABLES

MIL TYPE - RG-156/U MIL-C-17/101



SPECIAL CHARACTERISTIC CABLES

MIL TYPE - RG-65A/U MIL-C-17/34



167.745

Figure 5-70.—Pulse and special characteristic coaxial cables.

Although series N 50-ohm and 70-ohm con- ectors do not mate, 70-ohm cables may be ed with 50-ohm series N connectors where mpedance matching is not critical. Series N onnectors are completely weatherproof.

Series C connectors are similar to 50-ohm ries N connectors in that they are used with e same cables, are weatherproof, and can be used up through microwave frequencies. How- ver, they are mechanically and electrically perior to series N connectors. Series C con- ctors feature bayonet-lock type coupling for ick connect and disconnect, an improved cable lamping mechanism for better cable grip with minimum cable indentation, and are intended for use up to 1,000 volts.

Series BNC connectors (fig. 5-72) are commonly used on small coaxial cables. All incorporate quick connect and disconnect bayonet-lock coupling and are weatherproof. Besides regular and modified low-voltage types of non-constant impedance, improved series BNC connectors are available which have a constant 50-ohm impedance and yield excellent electrical performance up to 10,000 megahertz.

Series HN connectors are weatherproof, high-voltage connectors of constant impedance for use with 50-ohm RF cables.

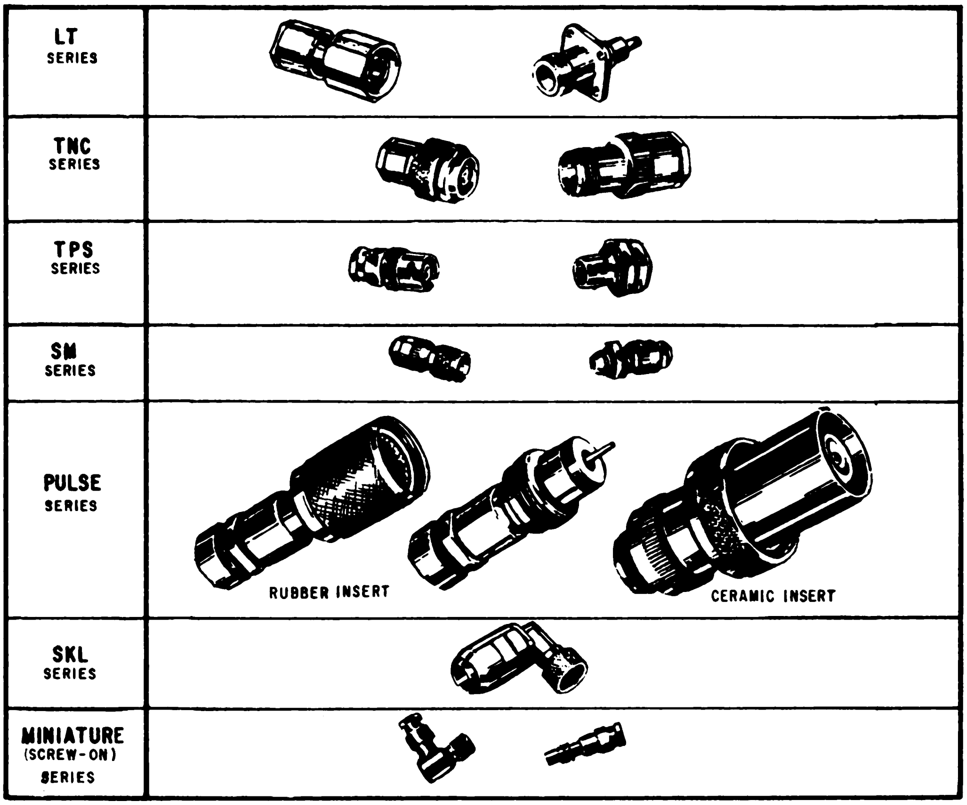


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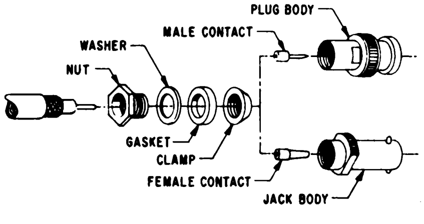
Figure 5-71.—Several typical coaxial connectors.



AQ.369

Figure 5-72.—Exploded view of a standard BNC connector.

Series LC connectors are large, 50-ohm, weatherproof connectors designed for applications involving the transmission of large amounts of RF power.

Series BN connectors are small, lightweight connectors (of non constant impedance) designed for use with the same coaxial cables which use BNC connectors. BN connectors are not recommended for applications at frequencies in excess of 200 megahertz unless electrical requirements of the circuit are not critical. They may be used at peak voltages up to 250 volts.

Series LT connectors are very similar in appearance to series LC; however, series LT differ not only in cable accommodation but are lighter than series LC connectors. Series LT connectors are large, 50-ohm, 5,000-volt connectors for use with Teflon RG-117/U cable.

Series TNC connectors are basically identical with series BNC connectors. The major difference is that TNC connectors have a threaded type coupling instead of the bayonet-lock coupling. Consequently, TNC connectors are usually preferred in applications which are subject to extreme vibration.

Series TPS connectors are weatherproof and designed to produce minimum electrical discontinuities in small size 50-ohm coaxial cable to a frequency of 10,000 megahertz. The conctors are rated at 1,500 volts rms at sea vel; their use is governed by the temperature nitations of their associated cables.

Series SM connectors are nonweatherproof tings for coaxial cables of 1/4-inch overall ameter and smaller. They may be used where ectrical matching is not required. The SM nnectors are smaller and contain fewer parts an the BNC series. The SM series employs a male center-conductor contact on plugs and a ale center-conductor contact on jacks and reptacles. However, for consistency in cataloging d usuage, a plug is still regarded as having male mating end and a receptacle or jack as male. The SM series is not intended to reace the BNC series except for internal equipent connections where weatherproofness is not quired.

The pulse connectors are designed for high-ltage pulse or direct-current applications. hey are nearly all weatherproof and available three types—rubber-insert, ceramic-insert, iaxial. The rubber-insert type PULSE conectors have a peak voltage rating of 5,000 volts. hey are designed principally for use with ables having an insulated Neoprene layer under e braid, such as RG-77/U and -78/U.

They may be used with cables employing a onducting rubber under the braid (such as RG-5/U, -26/U, and -64/U) provided special care s taken in assembling the connectors to these. he ceramic-insert pulse connectors are availble in small (type A) and large (type B) sizes. ype A connectors are designed for use with the ,000-volt RG-25/U, -26/U and type B with the 5,000-volt RG-27/U, -28/U cables. (Special are is required when assembling connectors to ese.) Pulse connectors tend to leak noise hich may interfere with communications equipent. Triaxial connectors are used in transission line applications where maximum RF hielding and minimum noise radiation are reuired. They are commercially available in izes of the same diameter as the BNC series nd C series (and possibly others). Some of hese connectors have been used in military quipment and some within-series adapters are ommercially available.

The SKL connectors were originally designed o provide a connection to a klystron tube. Newer lystrons are being equipped with BNC conectors. Various modifications were subseuently designed to provide general purpose able-to-cable connections and adapters.

Miniature connectors have a gold finish, employ screw type coupling, and Teflon dielectric. They have a nominal impedance of 50 ohms, a sea-level breakdown voltage of 1,500 volts rms, a practical frequency limit of 10,000 megahertz, and are designed for operation up to 200°C.

STUFFING TUBES AND KICKPIPES

Two classes of stuffing tubes are illustrated in figure 5-73. The class shown in part A is designed to be installed in the wall of an electrical appliance or fitting to permit the insertion of an electric cable. The cable is terminated in the appliance. The class shown in part B is designed to be installed in a deck, bulkhead, or hull to permit an electric cable to be passed through the structure. The cable is not terminated after passing through the tube but continues to some distant point.

Both classes of stuffing tubes are forms of packing glands and serve a common purpose in preventing the passage of liquids and gases at the point of cable entrance.

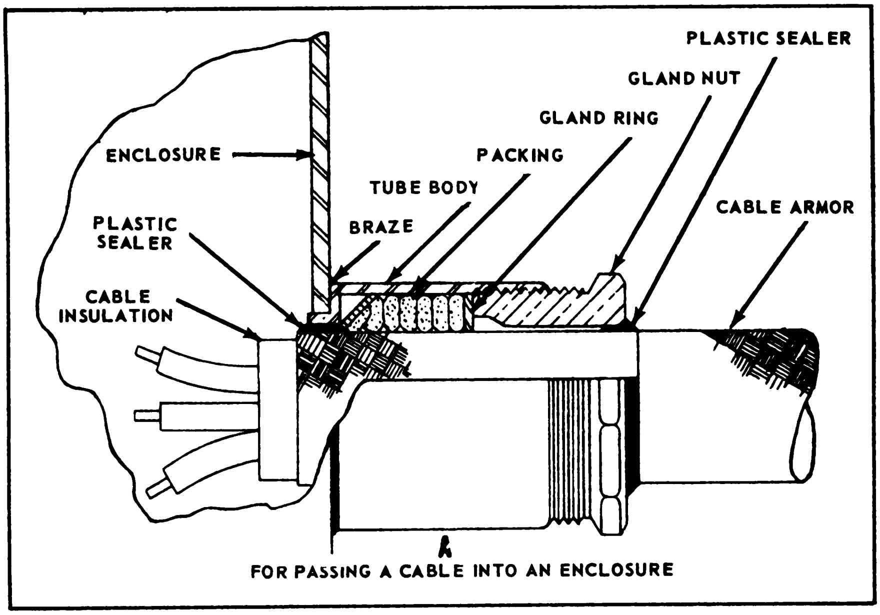
A kickpipe is a pipe used to pass cables through decks wherever cable protection from mechanical injury is needed. The minimum length of a kickpipe is nine inches and the maximum length depends on the requirements. If the length of the kickpipe is over twelve inches, the top of the kickpipe is secured by a brace.

More recently nylon stuffing tubes have been developed by the Naval Ship Systems Command, formerly the Bureau of Ships. These stuffing tubes (fig. 5-74) are extremely durable and will be used where practical when the present supply of metal stuffing tubes is exhausted.

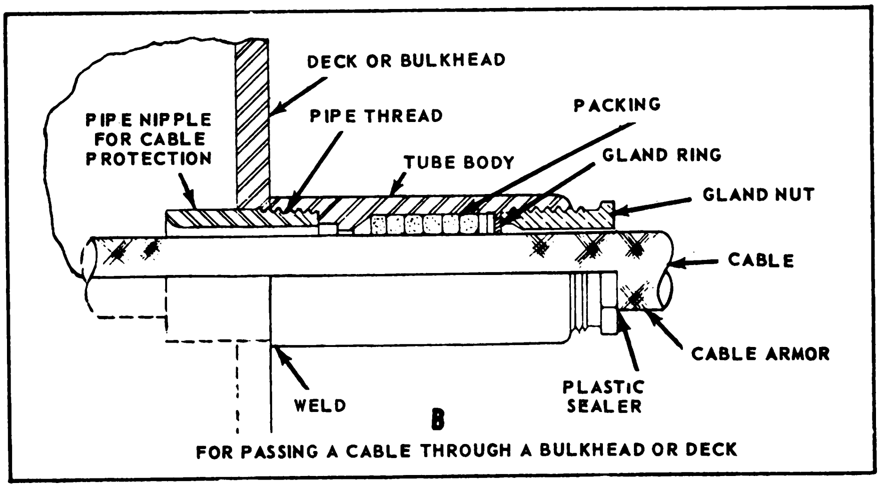
LAMPS

Lamps are devices that are used as sources of artificial light. They provide illumination for reading dials and to indicate the operational status of equipment, such as the mode of operation of a radar.

Lamps are a part of a light assembly. Generally speaking, a light assembly consists of a housing (fixture), a lamp, and a lens.



FOR PASSING A CABLE INTO AN ENCLOSURE



FOR PASSING A CABLE THROUGH A BULKHEAD OR DECK

12.77

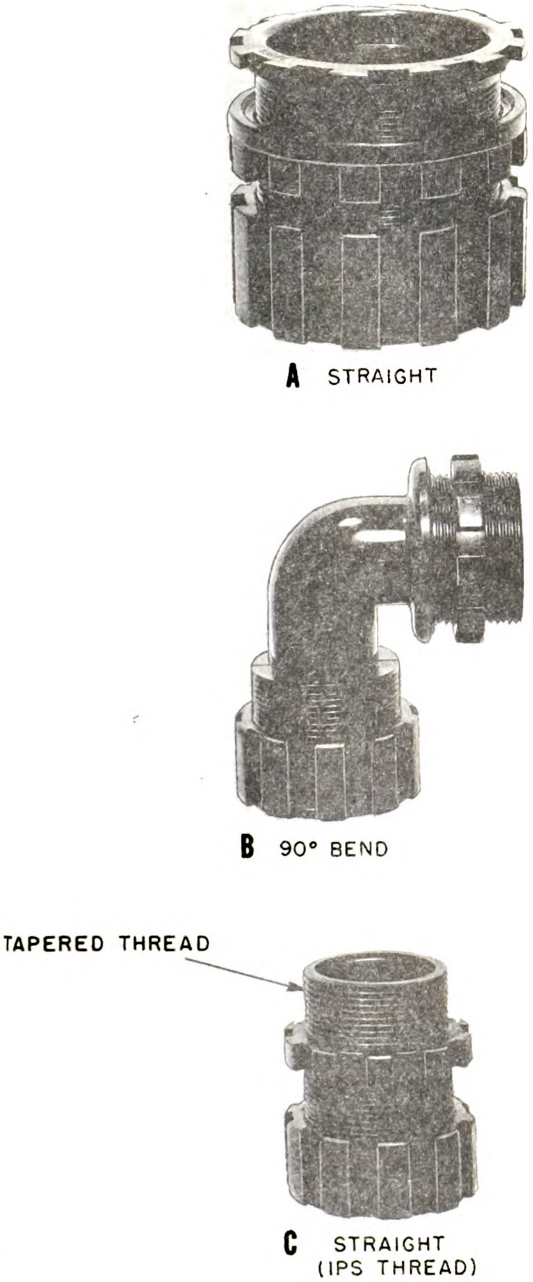
Figure 5-73.—Types of stuffing tubes.

The parts of a lamp are the bulb, filament, and base. Incandescent lamps vary chiefly in ELECTRICAL RATING, BASE TYPE, BULB SHAPE, and BULB FINISH.

The ELECTRICAL RATING is usually expressed as combinations of the following items: volts, watts, amperes, and candlepower. (Candlepower is the luminous intensity expressed in candles and used to specify the strength of a light source.) The lamp rating is marked on either the base or the bulb of the lamp. In the case of small lamps, the electrical ratin is usually replaced by an identifying number.

Base Type

BASE TYPES vary as to size, number o electrical contacts, and the method of securin in a socket. The most common bases are th single or double contact bayonet (push in an turn) type. These are desirable for shipboar



12.78

Figure 5-74.—Nylon stuffing tubes.

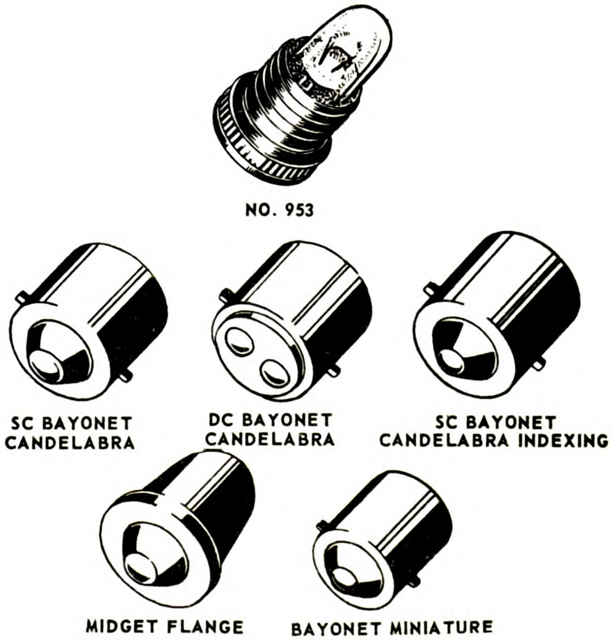
use since they lock in the socket and do not become loose because of vibration. The single contact is used in single-wire systems. In this system one side of the lamp filament is soldered to the base and the other to the contact. The double contact is used where the single-wire system is not practicable. In this system the filament is connected to the contacts and does not make an electrical connection to the base. Double contact bases are also used for dual filament lamps. The single and double contact type lamps cannot be used interchangeably.

Some bases are of the screw type but they find limited use because they loosen easily. Figure 5-75 shows some of the popular types and sizes of lamp bases.

The sizes of lamp bases are classified by the following terms: miniature, candelabra, intermediate, medium, and mogul. The smaller sizes (miniature and candelabra) are used extensively in instrument panel lighting.

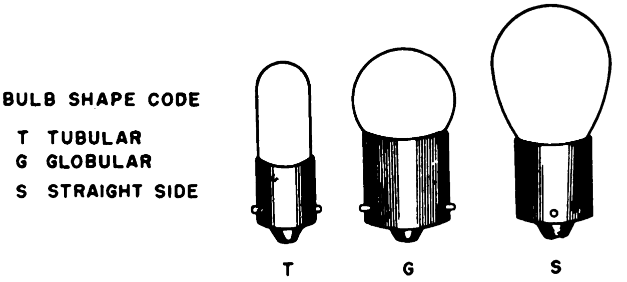
Bulb Shapes

BULB SHAPES are designated by the combination of a letter and a numeral. The letter designation indicates the shape of the bulb in accordance with a code, and the number is a measure of the approximate maximum diameter



12.79

Figure 5-75.—Lamp bases.



12.80
Figure 5-76.—Common bulb shapes.

of the bulb in eights of an inch. The shapes of the more common glass envelopes are as follows:

"G"—globular
"T"—tubular
"S"—straight side
"PAR"—parabolic

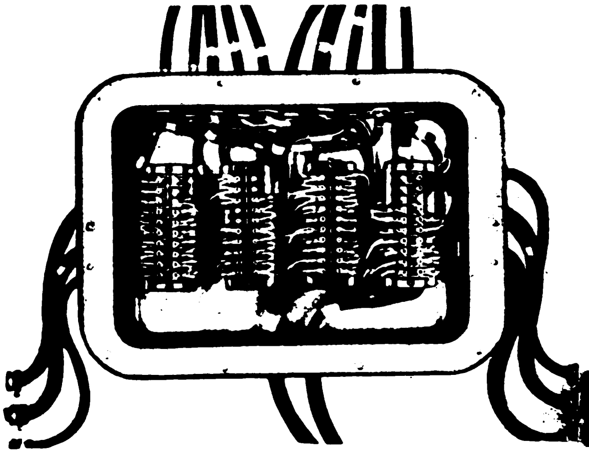
For example, a bulb designated as T-6 has a tubular shape and a diameter of 3/4 inch. Figure 5-76 shows some of the more common bulb shapes.

TERMINAL BLOCKS

As pointed out earlier, cables are going to be used to carry electrical energy from one equipment to another. This electrical energy many be to satisfy the power requirements of the receiving equipment or it may be electrical signals which represent fire control data such as synchro signals and radar video signals.

A Missile Fire Control System contains hundreds of these cables and many are multiple-wire cables. Each cable will terminate at or within some piece of equipment.

At the equipment, a means must be provided for distributing or routing the electrical energy to or from the various points within the equipment. Terminal blocks are used for this purpose.



167.59
Figure 5-77.—Power junction box, UD 62.

The power junction box (fig. 5-77) is a bulkhead-mounted component which is used to route primary power from a power control assembly to other units of a missile guidance radar set. This unit contains four terminal blocks.

The method of identifying a particular terminal connection requires knowledge of the equipment involved, the particular terminal board within the equipment, and the terminal number.

Missile Fire Control equipment has some form of equipment identification number. In this case it is Unit Designation (UD) 62. Every terminal block is assigned a number. The terminal block may or may not have an A or B side. Finally, the terminal point is assigned a number. We now have all that is necessary to identify a particular terminal point. Let us see how it is done. The expression, TB(62) 2A-6, tells you to go to equipment UD 62, find the A side of terminal block 2, count to the sixth connection point. You are then at the designated terminal point.

CHAPTER 6

FUNDAMENTALS OF ANALOG COMPUTERS

There are two distinct branches of the comuter family. One branch is descended from the cus, a mechanical extension of the idea of inger (digit) counting. It uses digits in the form f pulses and the absence of pulses to express umbers, and is therefore called a digital comuter. In other words, it simply counts. The ther member of the family, the ANALOG comuter, measures some continuous quantity such s the value of a voltage. The measured voltage epresents or, mimics or, simulates or, to use more elegant word, is analogous, to some uantity such as distance, speed, angle, weight, nd time.

Besides being classified by how they calcuate, digital and analog computers can be classiied physically and functionally. Physically, comuters are classified as mechanical, electronic, nd electro-mechanical. The classification of an nalog computer is determined by the type of evices used in its construction. Analog comuters are composed of computing devices that can be scaled to represent quantities: mechanical, electromechanical, or electronic.

Mechanical—This category includes differentials, linkages, cams, slides, multipliers, and component solvers. If you want to broaden your knowledge of the computer field, you will find a description of these elements in Basic Machines, NavPers 10624A.

Electromechanical—In this type of analog computer, problems are solved by using combinations of electrical signals and mechanical motions; for example synchros, potentiometers, and resolvers. All analog computers in the surface missile system field use these devices extensively. And so do data converters and coordinate converters, which are analog computers with names that reflect their function.

Electronic—Mathematical processes are solved by using voltages only; for example amplifiers, summing networks, and differentiating and integrating circuits.

Functionally, there are as many types of computers as there are problems; for example, the coordinate converter, the data converter, the ballistic computer, and the steering computer.

Analog computers make use of such electrical computing elements as:

- Vacuum tube and transistor amplifiers
- Electrical networks for addition and subtraction
- Resolvers for resolving a vector into its two components, for solution of right triangles and coordinate rotation
- Potentiometers for multiplication
- Function potentiometers and networks for generation of non-linear functions.

PRINCIPLES OF ANALOG COMPUTERS

An analog computer simulates a mathematical problem in a physical system. In fire control computers the mathematical problem is duplicated using mechanical, electrical, and electronic computing circuits or components. The physical values in these systems are measurable. This is a rather abstract idea, so we will illustrate it. As an example we will use the computation for future target height Rv_2. The formula for Rv_2 is:

$$Rv_2 = R \sin E + T_2 \cdot DMv$$

Where:

R = present range
E = present elevation
T_2 = time of flight
DMv = linear rate at which target height is changing

Solving the formula requires four separate operations:

1. Find sin E
2. Multiply sin E by R
3. Multiply T_2 by DMv
4. Add R sin E and T_2 DMv

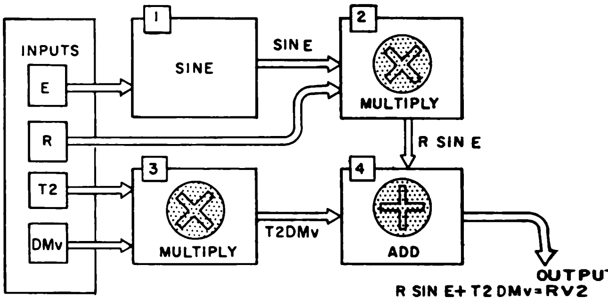
In figure 6-1 these operations are shown in an arrangement similar to that found in a computer. The mathematical functions are shown in block form. By substituting computing elements, we can mechanize the formula. R and E are measured by the director, and are known quantities. T_2 and DMv are computed quantities which we will assume are correct, for they enter the formula with definite values.

Each element in the figure solves a discrete problem which is an integral part of the overall problem. There is practically no delay in an element arriving at an answer; once its inputs are set the answer is present as an output. The input values of R and E are represented by a voltage and an angle respectively. An infinite number of combinations of these values are possible, but they can be represented quickly and accurately in their analogous systems. As a target moves in or out along the range scale, its voltage representation follows it in a linear manner along the voltage scale. The voltage, within its limits of operation, is a continuous, uninterrupted representation of the numerical value of range. Thus, although we have two dynamic input quantities, the answer is always available.

INTRODUCTION TO SCALE FACTORS

At one time or another, you have probably used a road map to estimate the distance from one point to another. Usually, at the lower edge of the map, there is a scale, which is graduated in miles/inch. This ratio is called a scale factor. It states the ratio of the scaled drawing to the actual area that the map represents. By measuring the distance between points in inches and multiplying this number by the miles/inch, obtained from the scale, you get an estimate of the number of miles between points.

Another familiar example of a scale factor is the mileage indicator in an automobile. Here, during design, the engineer determines how far the car will move for one revolution of the drive shaft, then connects a counter to it, and scales the counter to represent the distance the car is driven. In reality, all the counter is doing i counting the drive shaft revolutions. Here, th scale factor is the ratio of the distance covere to one revolution of the drive shaft.



92.5

Figure 6-1.—Mathematical operations.

Just as the inches on a road map and th revolutions of the drive shaft are used as scale factors to represent some physical knowledge the elements of analog computer are scaled t represent physical quantities within the computer

SCALE FACTORS IN ANALOG COMPUTERS

A scale factor, selected for use in an analo computer, is a constant that relates a compute variable directly to a variable of the problem being solved: in other words, it is the ratio of the analog units to the equation units, thus:

$$\text{Scale Factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

The most commonly encountered analog units are volts and shafts revolutions. These analog units are used to represent the physical variables (or equation units) of the fire control problem, such as range, elevation, bearing, speed, initial velocity, and many others. The larger the scale factor is, the more accurate the results will be, or the larger the ratio of analog units to equation units the more accurate the results. When the statement is applied to scale factors in an analog computer, it can be illustrated in the following examples:

Example 1: If one revolution of a shaft represents 360°, the shaft has a smaller scale factor than one that is representing 10°.

$$\text{Scale factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

$$\text{Scale factor} = \frac{1\ \text{Rev}}{360^\circ}$$

$$\text{Scale factor} = 0.00277\ \text{Rev/Deg.}$$

$$\text{Scale factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

$$\text{Scale factor} = \frac{1\ \text{Rev}}{10^\circ}$$

$$\text{Scale factor} = 0.1\ \text{Rev/Deg.}$$

Since 0.00277 is less than 0.1, the scale factor for a shaft representing 360° is smaller than for one representing 10°.

Example 2: If 1 volt represents a distance of 100 yards, the scale factor is larger than when 1 volt represents 1,000 yards.

$$\text{Scale factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

$$\text{Scale factor} = \frac{1\ \text{Volt}}{100\ \text{Yards}}$$

$$\text{Scale factor} = 0.01$$

$$\text{Scale factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

$$\text{Scale factor} = \frac{1\ \text{Volt}}{1{,}000\ \text{Yards}}$$

$$\text{Scale factor} = 0.001$$

Since 0.01 is larger than 0.001, the scale factor for 1 volt representing 100 yards is larger than when 1 volt represents 1,000 yards.

The actual scale factor used in analog computers depends upon the voltage suitable for the computer circuits. In most computers, a variable in an equation is represented by as large an electrical or mechanical quantity as possible. This gives a larger analog unit to equation unit ratio, thereby increasing accuracy.

When the terms large scale factor and small scale factor are used in later discussions, you should have a clear concept of their meaning.

CHOICE OF SCALE FACTORS

In electronic elements, circuit noise affects the values. Also, the saturation point of amplifiers limits the scale values. Furthermore, if the scale factor is too large, the size of the resistors, condensers, and other components in the circuit would have to be increased in order to handle the increased power required. This would also create a problem of heat dissipation.

The problem of selecting a scale factor, for electronic elements, is illustrated by the following:

Consider a scale factor of 1 volt/4000 yards; one millivolt (average) of noise in the circuit would represent an error of only 4 yards. But with a scale factor of 1 volt/12000 yards, a millivolt (average) of noise would cause an error of 12 yards. Thus with a small scale factor, a given amount of noise represents a greater error.

On the other hand, if a very large scale factor, such as 1 volt/yard, is used, the problem of handling large voltages is encountered. If the computer had to handle 100,000 yards with a scale of 1 volt/yard, the amplifiers and power sources would have to handle and supply 100,000 volts. This is nearly impossible.

Because of their low noise level, transistors are used extensively in computers. Small scale factors of 1 volt to 8,000 or more yards are common in transistorized analog computers.

SCALE FACTOR ANALYSIS

You must have a clear concept of scale factors, analog units, equation units and their relationship to each other.

Given: The maximum range of a computer is 240,000 yards; the maximum voltage that the amplifiers can handle is 12 volts. The scale factor is then equal to:

$$\text{Scale factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

$$\text{Scale factor} = \frac{12\ \text{Volts}}{240{,}000\ \text{yards}}$$

$$\text{Scale factor} = \frac{1\ \text{Volt}}{20{,}000\ \text{yards}}$$

This scale factor states that 1 volt is equal to, or represents, 20,000 yards.

If the scale factor and the analog units are known, the equation units may be found as follows: (assuming an analog voltage of 3 volts).

$$\text{Equation units} = \frac{\text{Analog Units}}{\text{Scale Factor}}$$

$$\text{Equation units} = 3 \text{ volts}/\frac{1 \text{ volt}}{20{,}000 \text{ yards}}$$

$$\text{Equation units} = 3\text{x}\frac{20{,}000 \text{ yds}}{1} = 60{,}000 \text{ yds}$$

If the scale factor and the equation units are known the analog units may be found as follows:

$$\text{Analog units} = \text{Equation units x scale factor}$$

$$\text{Analog units} = 60{,}000 \text{ yds x } \frac{1 \text{ volt}}{20{,}000 \text{ yds}}$$

$$\text{Analog units} = 3 \text{ x } 1 \text{ volt} = 3 \text{ volts}$$

In the maintenance of a computer, it is sometimes necessary to perform the above computations to check the scale factor, the accuracy of the analog voltage, and the overall accuracy of the computation. For some computers, the scale factor is listed at the top of each column for the various computing accuracy tests performed on the computer. For other computers, it is necessary to use the computer prints to obtain the scale factor. In many instances, you will find that the scale factor is expressed as a ratio of equation units to analog units. Example: 90,000 yards/volt, 6000 yards/rev. Don't let this confuse you. Both methods are accepted forms of expressing scale factors. However, when the scale factor is expressed in equation units/analog units (i.e., yard/volt), the smaller the scale factor the greater the accuracy.

ELECTROMECHANICAL COMPUTING ELEMENTS

An electromechanical computing element is one that has electrical parts as well as moving parts. Such basic elements as synchros, linear and nonlinear potentiometers, sine and cosine potentiometers, resolvers, and a-c and d-c generators are included in this category. Except for generators, you have been introduced to all these elements in previous chapters and in the basic training courses. Since the application of all these devices is a universal feature in Navy analog computers, these devices will be covered here in more detail to give you a solid background in how they work.

In an analog computer, these elements perform mathematical operations. The elements are then interconnected to solve equations. In each electromechanical computing element and throughout the computer, a physical quantit termed the computer variable, represents, or i analogous to, the problem variable.

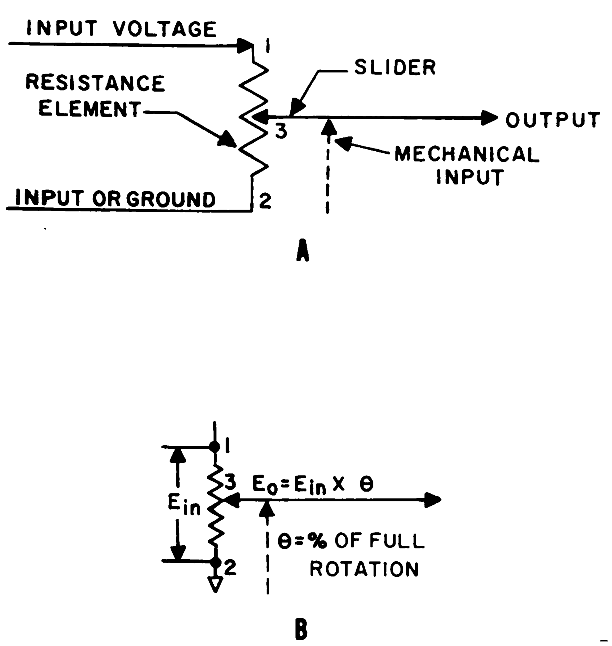
In a computer using electromechanical computation there are two types of analog variable voltages and mechanical displacement (shaft revolutions). These variables represent such physical variables as range, elevation, bearing, spee and initial velocity. Voltages, rather than currents, are used almost exclusively as the computing variable in modern analog computer using electrical computation, because voltage can be measured and recorded at any point i the circuit without disturbing (opening) the circui Therefore, electromechanical computing element convert mechanical displacements into voltages and appropriate scale factors are assigned t these voltages.

POTENTIOMETERS

Potentiometers or, as they are often calle "Pots" are the basic components used in analog computers to convert shaft positions to electrical voltages. In this conversion, the pot actuall multiplies the constant input voltage by the mechanical position of the slider. Pots are use extensively to multiply, divide, and generat nonlinear functions (sine, cosine, secant, etc.

A pot, shown schematically in figure 6-2A is a resistance element having terminals a each end and a sliding contact. The contac traverses the element from one end to the other varying the resistance between the sliding contact and one of the fixed terminals. Each termina and the slider are numbered; the slider usuall has the higher number. The resistance elemen of a precision pot is wire wound because wir has a lower noise level then carbon compoun or similar mixture.

The resistance element is wound on a cor called a mandrel, the shape of which depends o the design and function of the potentiometer. Fo a linear one-turn pot, the wire is evenly space on the mandrel which is then shaped to form a circle. This permits the slider to move mechanically through 360° of rotation; thus, the electrical resistance between the slider and one end o the pot varies directly with the mechanica position of the slider. For a linear ten-turn pot the wire is usually wound on a rod which i then shaped to form a helix, or spiral. Thi allows the slider to rotate as many as 10 ful revolutions. If 360° rotation of the slider is no required, the resistance element may be woun on a rectangular card. However, this type o



167.60
167.61

Figure 6-2.—A. Potentiometer schematic; B. Volts x motion multiplication.

pot is usually used as a control device rather than as a precision computing pot.

Types of Potentiometers

There are two types of pots used in analog computers: linear and nonlinear. A linear pot has its resistance element distributed evenly about its mandrel, so that each turn has the same amount of resistance. As the input shaft is rotated, the slider touches various windings and causes a change in resistance between the slider and the ends of the pot. With the pot energized, the voltage output varies linearly as the slider is moved from end to end because the voltage drop across each turn is the same.

A nonlinear pot is one whose voltage output does not vary at a constant rate as the slider moves. Nonlinear pots are sometimes referred to as shaped or tapered pots because the resistance element is wound on specially shaped mandrels, each turn having a different length of wire. Thus, the total resistance is distributed unevenly throughout the length of the pot. With the pot energized, the voltage output will vary in a nonlinear fashion as the slider is moved from one end to the other. Nonlinear pots can be constructed to produce practically any of the nonlinear functions present in the weapon control problem.

Representing Computing Variables Electrically

A potentiometer can also be thought of as a variable voltage source rather than a variable resistor since the input voltage is applied to the resistance element and a fraction of the voltage appears as the output between the slider and one of the pot. When the input voltage is constant, the potentiometer converts a mechanical input quantity into an electrical quantity. Thus any computer variable can be represented electrically by using a pot to make the mechanical to electrical conversion.

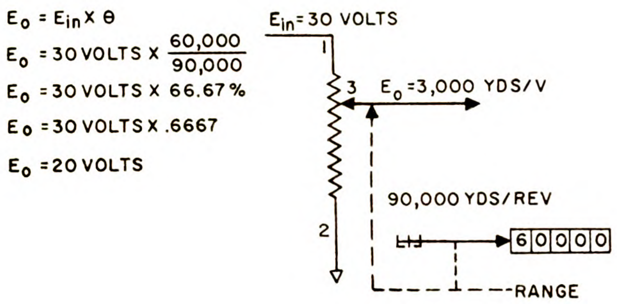
Here, the pot actually multiplies a voltage by a motion (slider position). The input voltage, E_{in}, is impressed across the resistance element through terminals 1 and 2. See figure 6-2B. The mechanical input, θ (THETA), is a percentage of full rotation of the slider. If the input voltage is 30 volts and the slider is positioned at 100% full rotation, then E_o = 30 volts x (1.0) = 30 volts.

When θ is at 25% full rotation, only one-fourth of the input voltage occurs at the slider: E_o = 30 volts x .25 = 7.5 volts. If θ is at 50% of full rotation, only one-half of the input voltage occurs at the slider: E_o = 30 volts x .5 = 15 volts.

When a suitable scale factor is assigned to the mechanical input, the output can represent any computer variable electrically. For example, assume that a one-turn potentiometer is used to represent a maximum range of 90,000 yards in a computer. For one full revolution of mechanical input the slider will move from terminal 2 to terminal 1. This amount of motion represents a range of 90,000 yards. The maximum range, or any fraction thereof, can be represented electrically by positioning the slider between terminals 2 and 1.

When a range counter indicates 60,000 yards, as shown in figure 6-3, the slider has moved through 66.67% of its travel from terminal 2, and 20 volts will appear at the output terminal 3. Thus by the multiplying feature of the potentiometer (volt x motion), range, represented by a shaft position and indicated by a counter, has been converted into an electrical voltage.

In addition to the mechanical scale factor assigned to a potentiometer, an electrical scale



167.62

Figure 6-3.—Potentiometer used to represent range electrically (360° rotaton).

factor is also assigned to the output voltage. The electrical scale factor is the yards/volt ratio. For the problem illustrated, the yards/volt ratio $= \frac{\text{yards/revolution}}{\text{volts/revolution}}$, or $\frac{\text{90,000 yards}}{\text{30 volts}}$. Thus the yards/volt ratio is 3,000 yards/volt. This indicates that each volt which appears at the slider represents 3,000 yards of range. Therefore, if 20 volts is measured at the output, and each volt represents 3,000 yards of range, then E_o = 20 volts x 3,000 yards/volt = 60,000 yards.

Another scale factor pertaining to the potentiometer can be very useful in determining how many yards an output voltwge represents. This scale factor is the ratio of the volts/revolution to the yards/revolution. For the problem illustrated, the volts/yards ratio =

$$\frac{\text{volts/revolution}}{\text{yards/revolution}}, \text{ or } \frac{\text{30 volts}}{\text{90,000 yards}}.$$

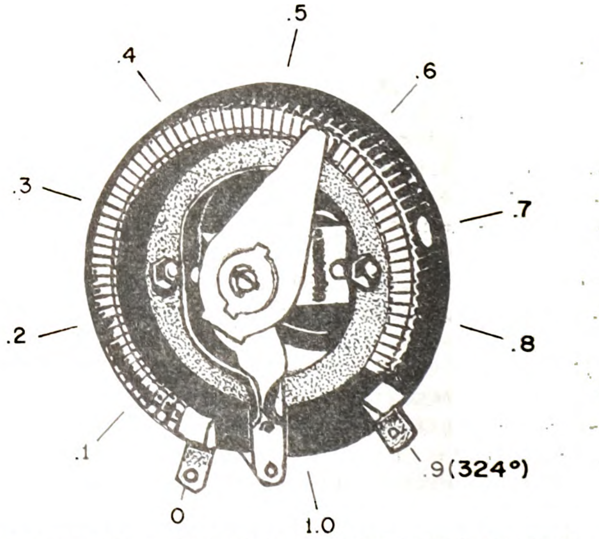
Thus the volts/yard ratio is .000333. This scale factor indicates that for each yard inserted into the pot mechanically there will be .000333 volt available at the output. Thus, if the output voltage were 6.666 volts, the number of yards this voltage represents can be determined as follows:

$$\text{Equation units} = \frac{\text{Analog units}}{\text{Scale Factor}}$$

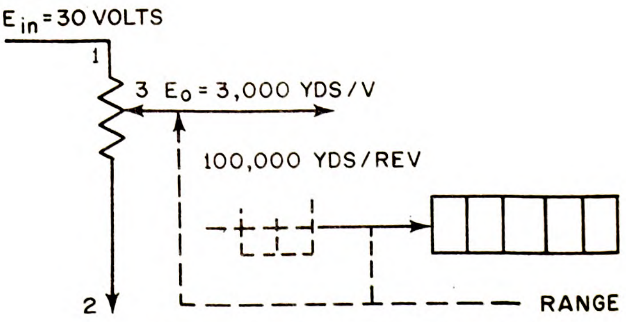
$$\text{Range in yards} = \frac{6.666}{.000333}$$

$$\text{Range in yards} = 20{,}018$$

When computing how many yards an output voltage represents, it is more convenient to use the scale factors of a pot rather than the percentage of full rotation of the slider. This is true because many one-turn pots actually do not rotate a full revolution. Furthermore, many 10 turn potentiometers only rotate 9.6 revolutions instead of 10 full revolutions. If the pot shown in figure 6-4, is used to represent a maximum range of 90,000 yards electrically, the scale factors assigned indicate that the potentiometer does not rotate a full revolution. If the total yards represented electrically (total yards = applied voltage x electrical scale factor) and the mechanical scale factor are not the same, then, the potentiometer does not rotate a full revolution.



A. MECHANICAL INPUT = DIAL READING X 100,000 YDS



B. ELECTRICAL REPRESENTATION OF (A)

167.63

Figure 6-4.—Potentiometer used to represent range electrically (324° rotation).

In this problem the mechanical scale factor dicates that one full revolution of the slider epresents 100,000 yards of range. The electrial scale factor and the applied voltage indicate at the maximum range represented electrially is 90,000 yards (30 volts x 3,000 yards/volt). herefore, a ratio exists between the total yards epresented electrically and the yards/revolution. hus, total revolutions of the pot are equal to

$$\frac{\text{total yards}}{\text{yds/rev}}, \text{ or } \frac{90,000}{100,000} = 0.9 \text{ revolutions.}$$

hus the pot will actually rotate 324° (360 x 0.9) o represent 90,000 yards of range.

What effect will this amount of rotation have n the volts/revolution, yards/volt, and volt/yard atio of the pot? Each ratio is compared for both ots to show which is affected.

You can see from table 6-1 that only the olts/revolution ratio is changed. The other ratios vill not change because the electrical scale actor for each pot is 3,000 yards/volt. Howver, if each pot is rotated the same number f degrees, the percentage of full travel, the utput voltage, and the number of yards repreented electrically are different for the two pots. n figure 6-5, each slider has been rotated 80° from terminal 2. The percentage of full ravel, the output voltage, and the yards repreented by each pot are computed for a mehanical input of 180°.

Double-ended Potentiometers

A potentiometer can be used to represent a computer variable that may be either plus or minus with respect to a zero reference. In this case, both ends of the pot are energized, one with a plus voltage and the other with a negative voltage. The center of the pot will represent the zero reference. The center may or may not be grounded.

When used this way, the pot still multiplies a voltage by slider position. However, when the slider is at the center of the resistance element, the output voltage is zero. Therefore, the center of the pot is the point of reference from which the percentage of rotation is measured. If the pot is energized with + and - 16 volts (as shown in fig. 6-6) and the slider is positioned one-quarter of a revolution from the center (zero reference) of the pot (this amount of slider travel is one-half of the available slider travel from the center to the end of the pot), then the output voltage, E_O, is computed by multiplying the input voltage, 16 volts, by twice the percentage of rotation of the pot. Therefore, $E_O = 16 \times 2(0.25) = 8$ volts. The output voltage will be either plus or minus depending on the direction of slider movement from the reference point.

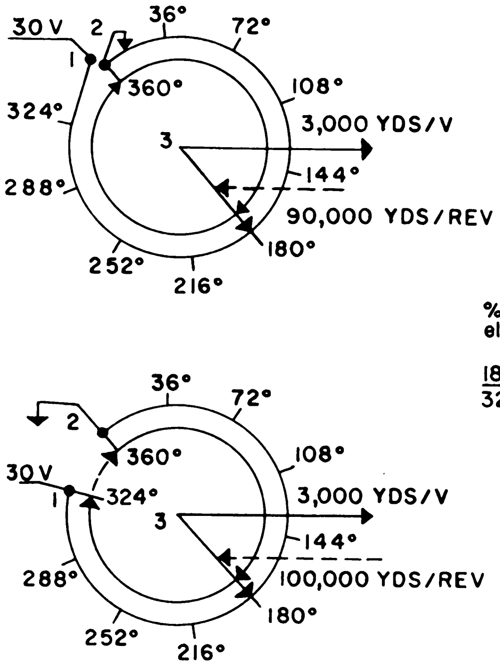
The potentiometer in figure 6-6 electrically represents a rate whose maximum limits are + and - 400 knots; thus it is possible for the rate to change a total of 800 knots. The travel of the slider from one end to the other will represent 800 knots, and if a one-turn potentiometer is used the mechanical scale factor must be 800 knots/revolution. The difference in voltage between each end of the one-turn potentiometer is 32 volts, which represents 800 knots. Therefore, the following ratios can be written for the potentiometer:

Volts/Rev = 32 volts/revolution

Table 6-1.–Volts/revolution, yards/volts, and volts/yard ratio

RATIO	90,000 YDS/REV POT	100,000 YDS/REV POT
Volts/Rev	$\frac{30 \text{ volts}}{1 \text{ rev}}$ = 30 volts/rev	$\frac{30 \text{ volts}}{.9 \text{ rev}}$ = 33.333 volts/rev
Yards/Volt	$\frac{90,000}{30}$ = 3,000 yards/volt	$\frac{100,000}{33.333}$ = 3,000 yards/volt
Volts/Yard	$\frac{30}{90,000}$ = .000333 volt/yard	$\frac{33.333}{100,000}$ = .000333 volt/yard

167.746



% of full travel of slider on resistance element is:

$\frac{180°}{360°} = .50$ or 50%.

$E_0 = E_{in} \times \theta$

$E_0 = 30v \times .5$

$E_0 = 15$ volts

E_0 = in yards is:

15v x 3,000 Yds./V = 45,000 Yds.

% of full travel of slider on resistance element is:

$\frac{180°}{324°} = .55555$ or 55.555 %

$E_0 = E_{in} \times \theta$

$E_0 = 30v \times .55555$

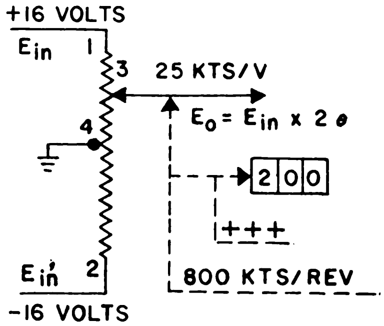
$E_0 = 16.6665'$volts

E_0 in yards is:

16.6665 v x 3,000 Yds/V = 50,000 Yds.

167.6

Figure 6-5.— Comparison of potentiometer outputs.



167.65

Figure 6-6.—Potentiometer representing a plus and minus rate.

Knots/Rev = 800 knots/revolution

$$\text{Knots/Volt} = \frac{800 \text{ kts/rev}}{32 \text{ volt/rev}} = 25 \text{ kts/v}$$

$$\text{Volts/Knot} = \frac{32 \text{ volt/rev}}{800 \text{ kts/rev}} = .04 \text{ volt/kt}$$

If the slider is positioned to represent 20 knots, then the output voltage is determined a follows:

Equation units X Scale factor = Analog units. Thus:

200 knots X 0.04 volt/kt = 8 volts

Use of Multiturn Potentiometers

The choice of mechanical scale factors i very important when dealing with pots. You hav seen that the mechanical scale factor is alway

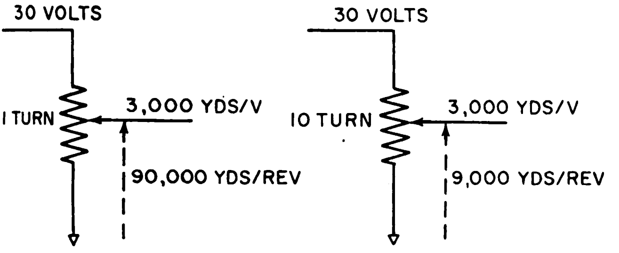


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Figure 6-7. — Using multi-turn potentiometers to increase accuracy.

compatible with the physical limits of a pot, and the electrical scale factor represents the mechanical input at all times. The use of multiturn pots increases the accuracy of the mechanical input so that lost motion (number of degrees the slider is in error) will not cause too large an error in the output.

Illustrated in figure 6-7 are two pots, used to represent 90,000 yards of range. The same electrical scale factor (3,000 yards/volt) is maintained for each. However, to increase the accuracy of the output per degree of error of the slider, one is a 10-turn pot. Each pot is energized by 30 volts. The slider of the one-turn pot will rotate 360° while the 10-turn slider will move through 3,600°. Table 6-2 can be used to compare the accuracy of the one-turn to 10-turn pots.

Sine and Cosine Potentiometers

A specially constructed potentiometer can be used to generate voltages proportional to the sine and cosine of a computer variable which appears as a mechanical rotation. This function generator is called a sine and cosine potentiometer.

The shape of the potentiometer card (fig. 6-8), is made proportional to the cosine function, then the resistance element is wound in a continuous layer around the card. The ends of the card are then joined together, thus forming a cylinder with two lobes. The ends of the resistance element are joined together to provide for continuous rotation of the potentiometer shaft.

The high points, or lobes, of the cylinder are connected to ground. A positive voltage is connected to one of the low points and a negative voltage to the other. The sine and cosine outputs are obtained simultaneously by having two sliders 90° apart and connected mechanically as a single unit but electrically isolated from each other and the potentiometer shaft.

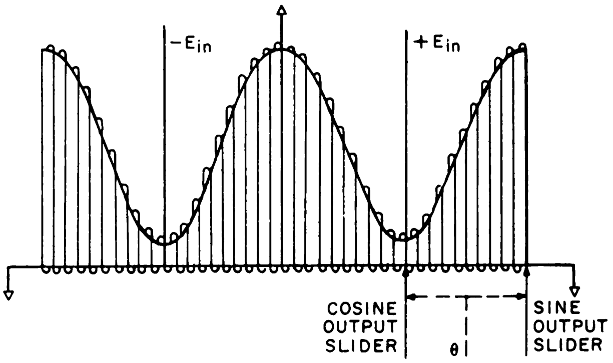
The potentiometer shaft is shown in its zero position. The sine output is zero volts because the slider is in contact with a grounded portion of the resistance element. The cosine output is a maximum plus voltage because the slider is in contact with the plus reference voltage. One full rotation of the shaft counterclockwise will reduce voltages that are proportional to the sine and cosine functions of the mechanical input. The polarity of the output voltages will be the same as the signs of the sine and cosine functions for all four quadrants.

RATE GENERATORS

A rate generator (tachometer), (fig. 6-9), puts out a voltage proportional to the magnetic field surrounding the motor and the speed of the rotor. In a rate generator the magnetic field is held constant but the speed of the rotor is variable. The amplitude or value of the output voltage is proportional to the velocity of the input signal (speed of rotation of the rotor).

Rate generators are used in computers to perform computations and as a source of stabilizing voltage for servoloops. This is changing mechanical information (speed) to electrical information.

The rate generator used in computers may be an a-c or a d-c generator. The d-c generator uses a permanent magnet to produce the magnetic field. The a-c generator is excited by an a-c voltage which produces the magnetic field in which the rotor rotates. The flow of energy is



55.3

Figure 6-8. — Sine and cosine potentiometer, cosine card type.

Table 6-2.—One-turn to two-turn potentiometer accuracy

	ONE-TURN POTENTIOMETER	TEN-TURN POTENTIOMETER
Total Travel	360 degrees	3,600 degrees
Yards/Volt	3,000	3,000
Yds/Degree	90,000 Yds/360° = 250	90,000 Yds/3,600° = 25
Volts/Degree	30 volts/360° = .08333	30 volts/3,600° = .008333
1° of error	.08333 volts or 250 yards	.008333 volts or 25 yards

167.747

from input winding, to rotor, to output winding. The output signal will be of the same frequency as the excitation voltage and is in phase or 180° out of phase with the input, depending on the direction of rotation. The a-c or d-c rate generator will theoretically produce a zero output when the rotor is stationary and will produce an output voltage whose amplitude and linearity are proportional to rotor speed, up to the saturation limit.

In some computers the rotor of the a-c rate generator is mechanically connected to the rotor of a servomotor. In other computers the rate generator and the servomotor are one unit; that is, each is a separate element, but they have a common rotor shaft. In either case, the speed of rotation of the servomotor provides the mechanical input to the rate generator.

In special cases, where a variation in the ratio of output voltage/revolutions per minute is critical, a temperature compensated rate generator is used. The output voltage of a temperature compensated rate generator is not affected by temperature.

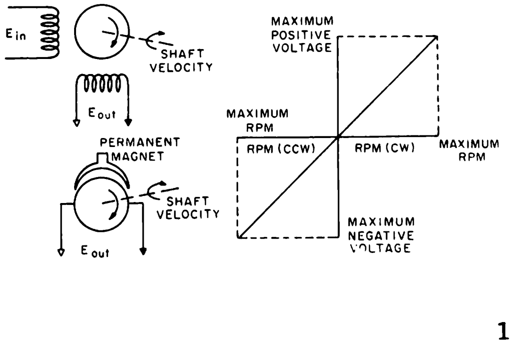


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Figure 6-9.—Output voltage versus RPMs for a-c and d-c rate generators.

ELECTRICAL AND ELECTRONIC COMPUTING ELEMENTS OF ANALOG COMPUTERS

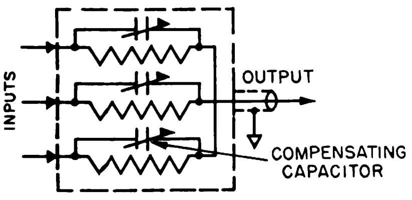
PARALLEL RESISTOR NETWORKS

Electromechanical computing elements convert mechanical computer variables into voltages, which in many instances are algebraically added together. The basic electrical computing element that does this job is the parallel resistor network. Its circuit arrangement is shown in figure 6-10.

The parallel resistor networks, called network boxes, have an output that is the algebraic sum of two or more inputs. The network box contains precision resistors and capacitors. The precision resistors are noninductive, wire-wound, and hermetically sealed in a metal can. The resistance of the resistors is normally kept within the 0.02 to 3.0 megohm range. The maximum is the point above which there would be too great a susceptibility to pick-up through inductive coupling between elements. A capacitor is connected across each resistor to compensate for any inductance created by the winding of the resistor. The capacitors are preset, and should never be changed. In later illustrations the capacitors are not shown since they only neutralize the inductance of a resistor.

The resistance can and capacitors are enclosed in a metal box, which is also sealed. The input and output leads are connected to pins mounted on a plug; therefore, the network box is a plug-in module. The output of the network box is always through a coaxial cable. This prevents stray pick-up (noise). The input connections are unshielded pins.

The principle advantage of using parallel resistors for the addition of voltages is simplicity; input signals may all be referred to a common grounded return. Without this feature all of the



12.85
Figure 6-10. — Parallel resistor network.

input sources would have to be electrically isolated from each other.

A network box can electrically produce the algebraic sum of two or more voltages, which are either in phase or 180° out of phase. Consider the circuit, in figure 6-11, where two equal voltages of the same polarity are to be combined. Voltages E_1 and E_2 are connected in series with resistors R_1 and R_2 respectively, and terminate at a common junction or node point. The voltage at the node point is not the actual sum of the voltages but is proportional to that sum. In this problem, the sum of the two voltages should be +20 volts; however, only 10 volts appear at the output. If one of the inputs is changed to 20 volts, the output should be 30 volts. But, only 15 volts will appear at the output. For these two examples, only one-half of the sum of the two voltages appears at the output. If a third input resistor were added to the circuit and all three of the input voltages were +10 volts, the output voltage would be +10 volts, or only one-third of the total input voltage. In each case there was a scale change, one-half of the total input for the first two problems and one-third of the total input for the last example. Therefore, the circuit is not always accurate for algebraic addition of analog voltages. Among its drawbacks are:

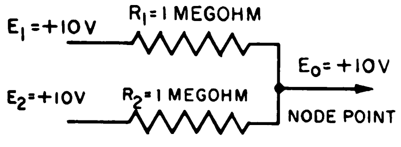


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Figure 6-11. — Parallel resistor summation network.

1. Loading at the output changes the effective value of the output impedance and produces a direct scaling error.

2. A scaling error is introduced if the number of input sources is changed.

3. Each of the input impedances, R_1, R_2, R_3 acts as a load on all of the inputs simultaneously. This causes interaction among the input voltages.

4. For accuracy the impedances R_1, R_2, R_3 should be high compared to the respective input impedances. This often raises the overall impedance level of the circuit to a point where pickup from extraneous sources may become a problem.

5. To minimize the effects of interaction among the various inputs, the output voltage should be as close to ground potential as possible. This results in a high attenuation of signal from input to output.

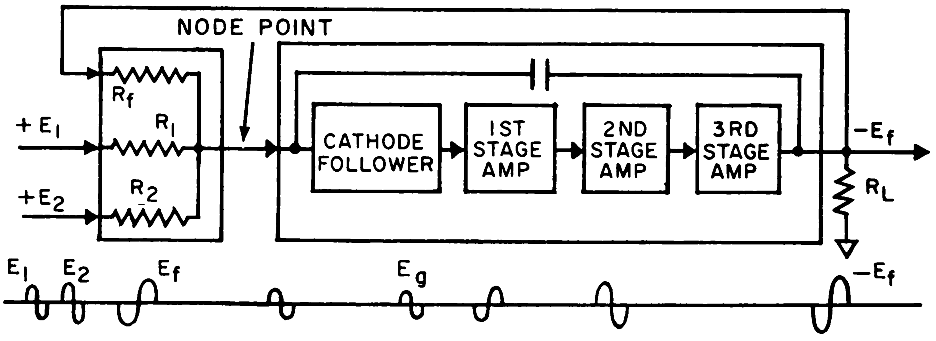
6. The accuracy of the parallel addition circuit depends directly upon the stability of the impedances, R_1, R_2, R_3 etc. Hence components must be precise.

All of the above points to the same thing; a feedback amplifier is needed in the circuit to prevent loading and to provide summation of voltages without a scale change unless desired.

Feedback Amplifier

The feedback amplifier (fig. 6-12), used with the network box is also a plug-in-module, and may use either tubes or transistors. Its components are interconnected by either wiring or printed circuits. Generally, each feedback amplifier has three stages of amplification; however, in some special cases it may have five.

When a feedback amplifier is in a computing loop, an additional resistor, Rf, designated the feedback leg, is required for the negative feedback. The negative output of the amplifier is impressed across the feedback resistor because the amplifier and resistor are in parallel. Therefore, the output of the network box, or node point, is automatically maintained close to ground potential. The feedback amplifier actually multiplies the small a-c output (Eg) by the amplifier gain factor (u). The amplifier solves the equation, -Ef = Eg. The forward gain of the amplifier is high (up to 20,000:1) to ensure accuracy. Negative feedback within the amplifier keeps the gain constant regardless of aging components, and it minimized harmonic distortion in the amplifier. The amplifier has exactly 180° phase



12.29

Figure 6-12.—Parallel addition circuit using a feedback amplifier.

shift from input to output. A capacitor, connected between the input and output, compensates for undesired phase shift.

The feedback amplifier features high input impedance and low output impedance. Its output is fed into a resistive load. If the load does not offer the correct resistance, a fixed resistor is connected across the amplifier output to provide the correct load.

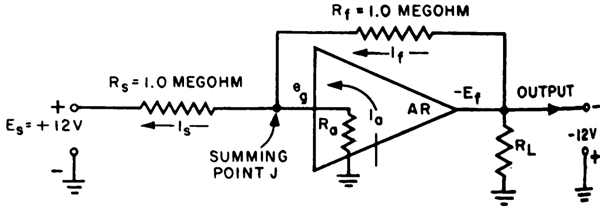
Even though the amplifier does amplify its input to produce the feedback voltage, the overall loop amplification is determined by the resistance ratio of the feedback resistor and the input resistors. This will be clarified later.

Although the feedback amplifier does not actually perform any computation other than the multiplication of its input voltage times the amplifier gain, it is always used with network boxes in computing loops which perform the functions listed below. The amplifier has various names: isolation amplifier, feedback amplifier, operational amplifier, computing amplifier, and summation amplifier. The various computing loops, in which feedback amplifiers are used, perform any or all of the following:

1. Reverse the sign of a voltage, with or without a change in overall loop amplification. Often, it is necessary to change the polarity of a voltage so that a plus and minus voltage is available for the solution of the problem. Also, at times it is necessary to change the overall loop amplification, which in turn changes the scale factor of the output with respect to the input.

2. Isolate and/or eliminate loading of one computing element from another. In electrical analo computers it is necessary to supply extreme accurate voltages from computing elements (po tentiometers, sine and cosine pots, and re solvers) to the same or other types of computin elements. If these elements are connecte directly, accuracy is lost due to loading.

3. Provide a voltage proportional to th algebraic sum of two or more input voltage Although a summing loop can be considered a a summation of analog voltages, the real jo of the loop is to determine the algebraic su of computer variables. These variables ar represented by the analog voltages; hence, scal factors are assigned to each. The computer vari ables that the voltages represent must have common reference axis; hence, the input voltage may be in phase or 180° out of phase. Otherwise an error will result.



12.29

Figure 6-13.—Sign reversing loop with unit gain (inverter).

Sign Reversing Loop with Unity Gain

The most basic loop employing a network box and feedback amplifier is the sign reversing loop (inverter). The loop reverses the phase of the input voltage and maintains unity gain (1:1). Here is how the loop works:

In figure 6-13, E_s and $-E_f$ are the effective input and output voltages, eg is the amplifier signal voltage; R_f is a fixed resistor located in the network box; and R_l is a fixed load resistor at the output of the amplifier.

If +12 volts is applied to the input leg, current flows from ground through the input impedance of the amplifier, through R_s to the signal source. This current is designated as I_a. It causes an input signal, eg, at summing point J, the input to the amplifier. The amplifier amplifies the input signal and provides degenerative (negative or inverse) feedback through R_f to summing point J. From point J, the feedback current flows through R_s to the signal source to ground and back to the amplifier. The feedback current is designated I_f. Thus, the current through R_s is:

$$I_s = I_a + I_f.$$

If the gain of the amplifier is designated as K, then, the output voltage, E_f, is K times as large as the input signal voltage, eg. Thus, the output voltage $E_f = -K(eg)$. In this equation, the minus sign before K indicates that there is a 180° phase displacement, or sign reversal, between eg and E_f. This is true because the amplifier has three stages of amplification. The gain of the amplifier is high; assume that it is 10,000. Therefore, the input signal, eg, need be only 1,200 microvolts to attain a maximum value of -12 volts for E_f. $(1/10{,}000 \times 12 = 0.0012$ volts).

According to Kirchhoff's Law of electrical current, the algebraic sum of the currents entering a junction such as summing point J must be equal to the sum of the currents leaving the junction. Since the amplifier is designed to have practically infinite impedance at the input and between the input and ouput, the only currents at summing point J are I_f and I_s . This equation neglects the very small voltage drop across the input impedance of the amplifier which will be discussed later. Therefore, the equation can be written: $I_s + I_f = 0$. Using this equation, we can solve for the output voltage if we know the values of R_s, R_f, and E_s. Thus the output voltage of the sign reversing loop is determined as follows:

$$I_s + I_f = 0$$

Rewrite as: $I_s = -I_f$

Substitute Ohm's Law: $\frac{E_s}{R_s} = \frac{-E_f}{R_f}$

Multiplying both sides by Rf: $R_f \left(\frac{E_s}{R_s}\right) = -E_f$

Substitute known values: $1.0\left(\frac{12}{1.0}\right) = -E_f$

Therefore: $E_f = -12$ volts

The equation,

$$E_s \left(\frac{R_f}{R_s}\right) = -E_f,$$

expresses the relation between the input and output voltages of the sign reversing loop. The ratio of the output to input voltage is shown to equal the resistance ratio R_f/R_s.

If we assigned the E_s input a scale factor of 100 knots/volt, then an input of +12 volts would represent 1,200 knots. To satisfy a zero, or null condition at summing point J, the feedback voltage must represent -1,200 knots. We can say, then, that there will be a null at summing point J when the inputs (+1,200 knots and -1,200 knots) are balanced. For a +12 volt input, the current through R_s and R_f is the same; $I = E/R = 0.000012$ amp. Therefore, this condition produces a zero, or null, at the input to the amplifier.

Features Provided by Negative Feedback

As explained in Basic Electronics, NavPers 10087-C, negative feedback occurs when the amplifier output voltage is fed back to the input out of phase with the input voltage. Negative feedback is also degenerative or inverse feedback. Negative feedback produces several important effects. One effect is to make the gain, or output-input voltage ratio, of the loop much less than the gain of the amplifier. The voltage fed back from the amplifier output opposes the input voltage supplied through the input resistor, R_s, thereby reducing the effective signal voltage at the input of the amplifier.

As a result of negative feedback, the loop output input voltage ratio is practically independent of the amplifier gain. If the amplifier gain should decrease, less voltage would be returned through the feedback path. Less voltage would be available to oppose the input voltage at the amplifier input. Consequently, the signal voltage, eg, would be greater; in fact, sufficiently greater to compensate very nearly for the loss of gain.

Another feature gained by negative feedback is an output voltage which is practically independent of output load. An increase in the load might tend to reduce the output voltage, but if the output voltage were reduced, less feedback would take place. Less feedback would increase the signal voltage, eg, and would thereby compensate for the reduction in output voltage. With negative feedback, the effective resistance between the output terminals of the amplifier is less than an ohm. Any load having a resistance measured in thousands of ohms, therefore, has small effect.

Scale Changing
(Multiplication and Division)

It is often necessary for the output of a loop to have a different unit/volt ratio than the input. This is referred to as a scale changing.

Consider the loop illustrated in figure 6-14. The loop's input voltage is +5 volts and each volt represents 100 knots; therefore, the input represents 500 knots. Using the formula previously determined,

$$-E_f = E_s\ (Rf/Rs)$$

the magnitude of the feedback, or output, voltage can be determined. Thus:

$$-E_f = E_s\ (R_f/R_s)$$

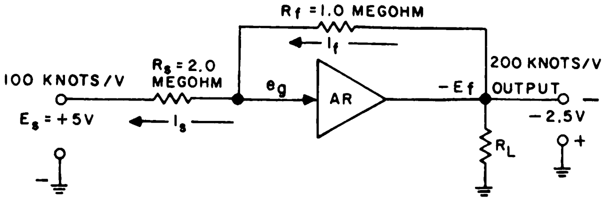
$$-E_f = 5(1.0/2.0)$$

$$E_f = -2.5 \text{ volts}$$

To determine the scale factor of the output voltage, multiply the input scale factor by the resistance ratio of the input leg over the feedback leg (2.0/1.0). Thus:

$$\text{Output scale factor} = \text{Input scale factor}\ (R_s/R_f)$$

$$\text{Output scale factor} = 100(2.0/1.0) \text{ or } 200 \text{ knots/volt}$$



167.73
Figure 6-14.—Basic circuit for scale changing.

Therefore, to satisfy a zero, or null, at the input to the amplifier only -2.5 volts with a scale factor of 200 knots/volt (-500 knots) is required to balance the input voltage, 5 volts at 100 knots/volt (500 knots).

The zero condition at the input to the amplifier can be seen more clearly if the current through resistors R_s and R_f is considered. If an input of 5 volts is dropped across resistor R_s, then the current through the resistor is:

$$I_s = \frac{E}{R}$$

$$I_s = \frac{5}{2{,}000{,}000}$$

$$I_s = 0.0000025 \text{ amps}$$

The current through R_s also flows through the feedback resistor, R_f; however, the resistance of this resistor is only 1 megohm. Thus the voltage across R_f is:

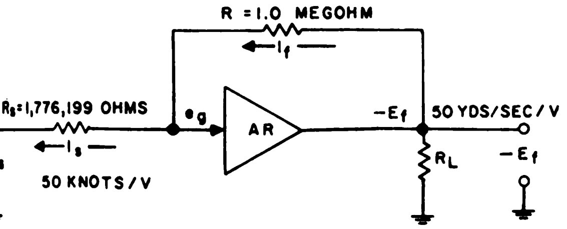
$$-E_f = I_f \times R_f$$

$$-E_f = 0.0000025 \times 1{,}000{,}000$$

$$E_f = -2.5 \text{ volts}$$

Because of the resistance ratio of the feedback leg to the input leg (R_f/R_s), the output of the amplifier will be only -2.5 volts to provide a null at the input of the amplifier. Thus, the scale factor of the input voltage has been changed from 5 volts at 100 knots/volt to 2.5 volts at 200 knots/volt.

The basic scale changing circuit provides an output of less than unity gain; yet, the output information represents the input information. But, ratios as common as 1:2 for the feedback to input leg are not often encountered in analog computer circuits. Usually, the ratio for the feedback to input leg has some odd ratio, not easily recognized. For instance, consider a circuit that might be used to convert knots into



167.74
igure 6-15.—A basic circuit for converting knots into yards/seconds.

rds-per-second. Knots can be converted to rds/second by multiplying knots by a constant 563.

Yards/second = Knots X 0.563

e ratio of R_f/R_s in the network box provides e constant, 0.563, for the loop illustrated in gure 6-15. Whenever possible, the resistance the feedback leg is kept at a value of 1 megohm, erefore, the input leg must have more resistance provide the correct ratio. Thus, the ratio of $/R_s$ is:

$$\frac{R_f}{R_s} = \frac{1,000,000}{1,776,199} \text{ or } 0.563$$

The scale factors assigned to the input and tput of the loop may seem confusing because e input scale factor is 50 knots/volt while the tput scale factor is 50 yards/second/volt. How- er, scale factors are usually expressed in its/volt; therefore, in order for the output represent the input, the output scale factor ready includes the constant, 0.563. This has en done mathematically during the design of the op.

A comparison of the output and input will show w the output scale factor is expressed as 50 rds/second/volt. When 50 yards/second ap- ars at the output of the loop, -1 volt is dropped ross the feedback resistor, R_f. The current rough R_f is:

$$= E = \frac{1}{1,000,000}; \text{ therefore, } I_f = 0.000001 \text{ amp.}$$

provide a null at the amplifier input, the input ltage will represent some value of knots that equivalent to 50 yards/second. Mathematically, 50 yards/second can be converted into knots by dividing by the constant, 0.563. This division would produce 88.81 knots. Electrically, the constant is provided by the ratio of the network box. As the input scale factor is expressed in knots/volt, and due to the ratio of R_f/R_s, the voltage felt across the input resistor, R_s, will be larger than the feedback voltage. Thus,

$$E_S = I_S \text{ X } R_S$$

$$E_S = 0.000001 \text{ X } 1,776,199$$

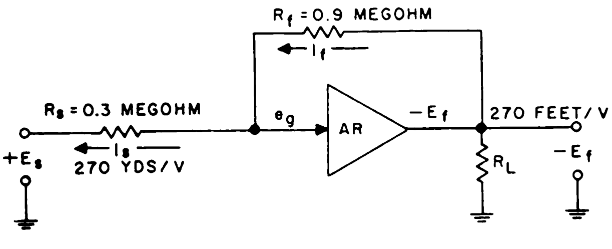
$$E_S = 1,776,199 \text{ volts}$$

Therefore, to provide a -1 volt output from the loop, the input voltage must be 1.776 volts. Since the scale factor of the input voltage is 50 knots/volt, this voltage represents 88.81 knots (1.776 x 50 knots/volt = 88.81).

Some input and output voltages and what each represents are tabulated in table 6-3.

Recall that the ratio of R_f/R_s controls the overall gain of the loop. The resistance value of the input resistor, for the loops discussed, was equal to, or larger than, the feedback resistor; therefore, the loop gain was equal to, or less than, unity. If the resistance of the input resistor is less than that of the feedback resistor, the overall gain of the loop will be increased. For instance, consider the circuit in figure 6-16 which might be used to convert yards into feet.

Since there are 3 feet in each yard, the ratio of R_f/R_s is selected as 3:1. The scale factor of the output voltage already includes the constant, in this



167.75
Figure 6-16.—A basic circuit for converting yards into feet.

Table 6-3.—Input/output voltage converted from knots to yards per second

Input Voltage	Represents Knots	Output Voltage	Represents Yards/second
1V	50	0.563V	28.15
2V	100	1.126V	56.30
3V	150	1.689V	84.45
4V	200	2.252V	112.60
5V	250	2.815V	140.75
6V	300	3.378V	168.90
7V	350	3.941V	197.05
8V	400	4.504V	225.20
9V	450	5.067V	253.35
10V	500	5.630V	281.50

167.7

case, 3. If 1 volt is the input to the loop the output will be:

$$-E_f = E_s\,(R_f/R_s)$$

$$-E_f = 1(.9/.3)$$

$$E_f = -3 \text{ volts}$$

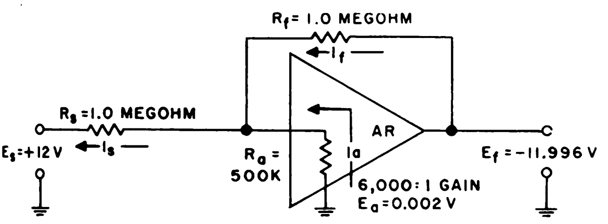
Therefore, this loop has an overall gain of 3:1, that is, 1 volt input will produce -3 volts at the output. If 1 volt at the output represents 270 feet, then, 3 volts x 270 feet = 810 fe which is the same as 270 yards.

Again, a comparison of output to input w show how the output scale factor is expres in feet/volt while the input scale factor is in yar volt. The ratio of R_f/R_s is such that o .333 volts is required at the input of the l to produce a -1 volt output. Several input- output voltages and what each represents tabulated in table 6-4.

Table-6-4.—Input/output voltage converted from yards to feet

Input Voltage	Represents	Output Voltage	Represents
0.333V	90 yards or 270 feet	1V	270 feet or 90 yards
0.667V	180 yards or 540 feet	2V	540 feet or 180 yards
1.000V	270 yards or 810 feet	3V	810 feet or 270 yards
1.333V	360 yards or 1,080 feet	4V	1,080 feet or 360 yards

167.



$I_s = I_a + I_f$

I_s = E/R ; 12/1,000,000 = 0.000012 amp OR 12 μa.

I_a = E/R ; .002/500,000 = 0.000000004 amp OR 4000 μμa.

$I_f = I_s - I_a$; I_f = 12 μa − 4,000 μμa = 11.996 μa.

$E_f = I_f \times R_f$; E_f = 1.0 MEGOHM X 11.996 μa = 11.996 VOLTS. THUS, THE OUTPUT IS 0.004 VOLTS LESS THAN THE INPUT.

167.76

Figure 6-17. — Loss of output voltage due to input impedance of amplifier.

GAIN COMPENSATING RESISTOR

During the discussion of the various loops, the slight voltage drop across the input impedance of the amplifier, as mentioned earlier, has been neglected. A close look at the overall circuit shows that the output is not quite equal to the input if this is neglected. The loop diagrammed in figure 6-17 uses a low gain amplifier to illustrate the loss.

To correct this slight loss, a gain compensating resistor, R_g, is placed in series with the feedback resistor (fig. 6-18). The value of the resistor is chosen so that with a +12 volt input, the output is exactly -12 volts.

In addition to compensating for the slight drop across the amplifier, the gain compensating resistor also reduces the feedback current by the exact amount of I_a so that the original assumption where I_a was assumed to be zero is now compensated for because $I_s = (I_f - I_a) + I_a$. Therefore, $I_s = I_f$ is a true statement.

The size of the gain compensating resistor can be computed using the current through the feedback leg and the voltage dropped across R_f. The voltage drop across R_g is determined as follows; (using values determined in figure 6-17):

$$E_g = E_s - E_f$$

Thus E_g = 12 - 11.996, or 0.004 volts.

The current through R_g is the same as that through R_f, thus,

$$I_g = I_s - I_a;$$

I_g = 12 μa - 4000 μμa, or 11.996 μa

Substituting these values into the formula,

$$R_g = \frac{E_g}{I_g},$$

the value of the gain compensating resistor is determined. Thus,

$$R_g = \frac{0.004}{0.000011996} \text{ or } 333.45 \text{ ohms.}$$

The feedback resistor and gain compensating resistor are in series; therefore, the total resistance of the feedback leg is:

$$R_{tf} = R_f + R_g \,;\, R_{tf} = 1{,}000{,}000 + 333.45 =$$

$$1{,}000{,}333.45 \text{ ohms.}$$

With more resistance in the feedback leg than in the input leg, the amplifier will produce -12 volts, thus compensating for the loss of voltage due to the input impedance of the amplifier. Thus, the voltage out is:

$$E_{out} = I_f \times R_{tf};\ E_{out} = .000011996$$

$$\times\ 1{,}000{,}333.45, \text{ or } -12 \text{ volts.}$$

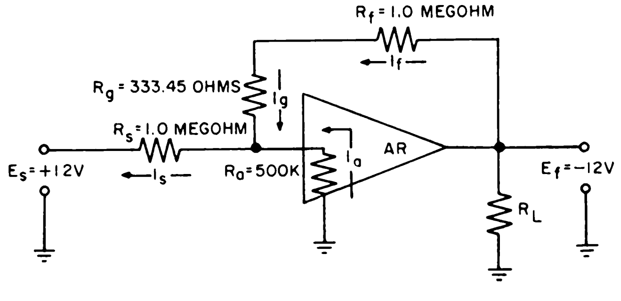


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Figure 6-18. — Gain compensating resistor used to increase output voltage.

Normally, the schematic of a network box does not show the gain compensating resistor, which does nothing but compensate for the loading effect of the amplifier.

From the discussion you can see that a particular network box is designed for an amplifier having a specific gain. The feedback amplifier has been standardized to a great extent and is interchangeable with another having the same drawing number.

SUMMATION OPERATIONS IN ANALOG COMPUTERS

Summation operations (addition and subtraction) are fundamentally important. Take the solution of the missile fire control problem. Here it is necessary to perform summation many times. In modern analog computers, the computer variables are converted into electrical signals, then combined in a loop called a summing computing loop. A typical summing computing loop includes either a feedback amplifier or a servomechanism, depending on whether an electrical or mechanical output is desired. If an electrical output is needed, an amplifier is used. If the output is mechanical, then a servomechanism is used. In either case the summation operation is performed by a network box.

BASIC SUMMING COMPUTING LOOP

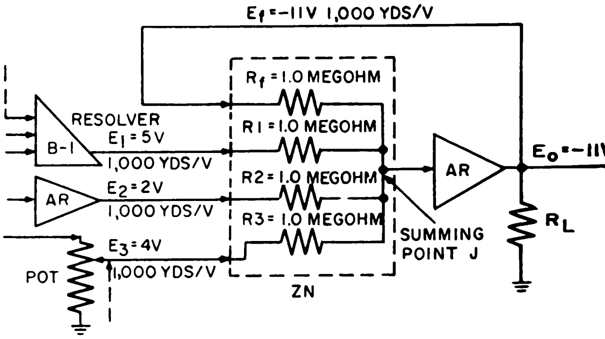
The loops discussed earlier, which used network boxes, did not add voltages. For a loop to perform summation, two or more input voltages are required. Such a loop is illustrated in figure 6-19. The loop determines the algebraic sum of three input voltages. To perform summation, a four-legged network box is used, three legs for the input voltage and the fourth leg for the feedback voltage. The feedback leg is sometimes referred to as the Great Equalizer because it carries the current that balances or nulls out the currents in the other legs.

The three voltages to be added have the same scale factor (1,000 yards/volt). The resistance ratios

$$(R_f/R_1 ,\ R_f/R_2 ,\ R_f/R_3)$$

are chosen to provide summation of the voltages without a scale change, therefore, the output voltage should be 11 volts with a scale factor of 1,000 yards/volt, or a total of 11,000 yards.

$$I_f = I_1 + I_2 + I_3$$



167,

Figure 6-19.—Basic summing computing lo

Substituting Ohm's Law:

$$E_f/R_f = E_1/R_1 + E_2/R_2 + E_3/R_3$$

Multiplying both sides by R_f:

$$E_f = E_1 (R_f/R_1) - E_2 (R_f/R_2) - E_3 (R_f/R_3)$$

Substituting known values:

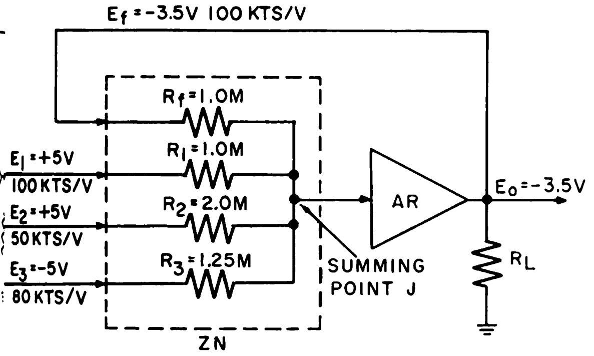
$$-E_f = 5(1/1) + 2(1/1) + 4(1/1)$$

$$-E_f = 5 + 2 + 4$$

$$E_f = -11 \text{ volts.}$$

As the ratio of the feedback leg to each of inputs is 1:1, then the scale factor of the o put voltage is the same as the inputs, or 1, yards/volt. Therefore, 11 volts at 1,000 yar volt represents a total of 11,000 yards. Th the summing computing loop uses a multi input network box to produce an output wh is the sum of its three inputs. The sign of output voltage is negative because there an odd number of stages in the amplifier. Ho ever, if a negative voltage cannot be used this stage of computation, a sign revers loop could be used to reverse the polarity the voltage.

Although addition has been explained as summation of voltages, the real job of summing computing loop is to add physic units, such as yards and knots. Therefore kno ledge in equals knowledge out. Thus each co puting loop will have scale factors assign



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igure 6-20.—Summation of voltages with dissimilar scale factors.

UMMATION OF VOLTAGES WITH ISSIMILAR SCALE FACTORS

In an analog computer, it is often necessary) add quantities that have different values of nits/volt (scale factors). To add these correctly, ll the inputs must be converted to a common cale, that is, the same unit/volt. The design ngineer selects the suitable ratios for the etwork box so that each input is converted to common scale. However, the ratios selected ust be such that the output cannot exceed the aximum rated output of the feedback ampli- er or the computer reference voltage applied) a potentiometer.

As illustrated in figure 6-20, three voltages, o positive and one negative, each with a differ- t value of knots/volt are to be added alge- aically by the summing computing loop. The gative input voltage will not present a prob- n as the current through R_3 will cause a sitive potential at summing point J, which effect will reduce the current through the dback leg. According to Kirchhoff's Law of ctrical current, the algebraic sum of the rrent entering a junction must be equal to e sum of the current leaving the junction. erefore, the following equation can be written:

$$I_f + I_3 = I_1 + I_2$$

e equation of the above can be rewritten as llows:

$I_f = I_1 + I_2 - I_3$, and used to compute the output voltage.

$$E_f/R_f = E_1/R_1 + E_2/R_2 - E_3/R_3$$

$$E_f = E_1\,(R_f/R_1) + E_2\,(R_f/R_2) - E_3\,(R_f/R_3)$$

$$-E_f = 5(1/1) + 5(1/2) - 5(1/1.25)$$

$$-E_f = 5 + 2.5 - 4$$

$$E_f = -3.5 \text{ volts.}$$

As R_f and R_1 have a 1:1 ratio, this sets the common scale factor for the output voltage. Thus,

Common output scale factor =
E_1 scale factor (R_1/R_f)

Output scale factor =
100 knots/volt (1/1), or
100 knots/volt.

The resistance value of the other two input legs is selected so as to convert the knots/volt ratio to the common scale of 100 knots/volt. Thus, the output scale factors for the other two legs are as follows:

Output scale factor =
E_2 scale factor (R_2/R_f)

Output scale factor =
50 knots/volt (2/1), or
100 knots/volt.

Output scale factor =
E_3 scale factor $(R3/R_f)$

Output scale factor =
80 knots/volt (1.25/1), or
100 knots/volt.

Therefore, the output factor is common for each of the three input voltages. Thus the summing computing loop has algebraically added the three voltages with different scale factors to produce an output of 3.5 volts, which represents 350 knots.

The summing computing loop just described is not suited for practical use, but is sufficient for explaining the summation of positive and negative input voltages and the principles of scale changing. Let's examine the reason for it not being practical.

When a network box is designed for use in a summing computing loop, the design engineer must take into consideration the maximum level

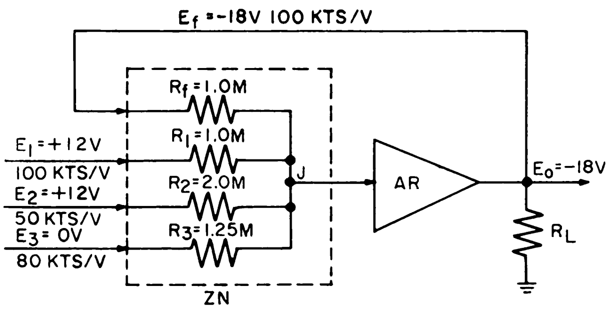

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Figure 6-21.—Impractical summing computing loop.

of the input voltages as well as the maximum output voltage. The ratio of the feedback leg to each input leg must be such that the amplifier will not saturate. The magnitude of the output voltage, along with the scale factor assigned, must be suitable for the next step of computation.

Different computers use different computer reference voltages. A typical example is 12 volts. Others are 16 volts, 20 volts, 24 volts, 30 volts, and 40 volts. If a computer used a 12-volt reference, all the resolvers, potentiometers, and feedback amplifiers are designed to handle this level of voltage. If it were exceeded in the problem computation, the amplifier would saturate and cause an error in computation.

Illustrated in figure 6-21 is the same summing computing loop previously described, except that the input voltages have been changed, but the scale factors are the same.

Summation of the input voltages should produce -18 volts, which is more than the amplifier can deliver. Thus, the amplifier is saturated, and an error exists.

Voltage Computation

$$E_f = E_1 (R_f/R_1) + E_2(R_f/R_2) - E_3(R_f/R_3)$$

$$-E_f = 12(1/1) + 12(1/2) - 0$$

$$-E_f = 12 + 6$$

$$E_f = -18 \text{ volts}$$

To prevent saturating the amplifier, different values of resistance for each of the input legs are incorporated in the network box. A summing computing loop that can perform summation is shown in figure 6-22.

Voltage Computation

$$E_f = E_1 (R_f/R_1) + E_2(R_f/R_2) - E_3(R_f/R_3)$$

$$-E_f = 12(1/1.5) + 12(1/3) - 0$$

$$-E_f = 8 + 4 - 0$$

$$E_f = -12 \text{ volts.}$$

A maximum input of + 12 volts is applied to two of the input legs as E_1 and E_2. Zero volts is applies as input voltage E_3. Under these conditions, the loop should produce a maximum output that is within the limits of the amplifier. Thus, with maximum input the output is as follows:

Output Scale Factor Computation

100 Kts/V(1.5/1) = 150 knots/volt

50 Kts/V(3/1) = 150 knots/volt

80 Kts/V(1.875/1) = 150 knots/volt

Special Divider Networks

In network boxes, it is common practice to use a feedback resistance of one megohm. With this value of R_f, the value of each input leg is calculated to obtain the correct ratio between the feedback leg and input leg so that all inputs are converted to a common scale.

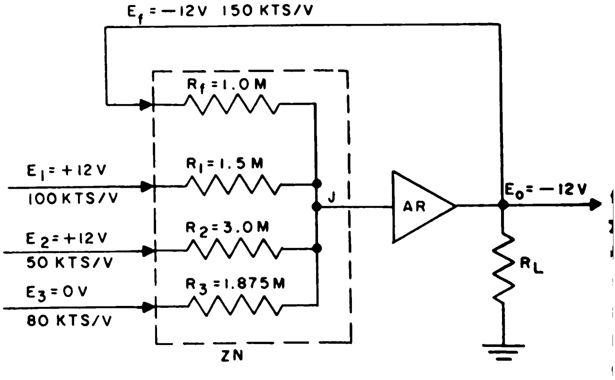

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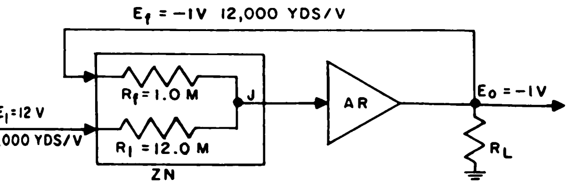
Figure 6-22.—A practical summing computing loop.



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ure 6-23.—Improper selection of resistor values.

wever, in computing the ratios it may be ind that the resistance of one or more of input legs may exceed three megohms. ice a three-megohm resistor is susceptible pickup through inductive coupling with other sistors in the network box, a special divider twork is substituted for the large resistor reduce its size but keep the computation same.

Illustrated in figure 6-23 is a circuit where ratio desired is such that to use a single sistor would require one which exceeds the ximum limit of three megohms.

The circuit provides a scale change of 1:12 ing a single resistor in the input leg. The ale factor of the input voltage is 1,000 yards/ lt. Due to the ratio between R_f and R_1, the tput voltage is -1 volt with a scale factor 12,000 yards/volt.

$E_f = E_1(R_f/R_1)$	Output scale factor = Input scale factor (R_1/R_f)
$-E_f = 12(1/12)$	Output scale factor = 1,000 yards/volt (12/1)
$E_f = -1$ volt	Output scale factor = 12,000 yards/volt

If such a situation arises during the design of computer, a single divider network would be bstituted for the large input resistor. Illus- ited in figure 6-24 is a circuit using a single rider. It will accomplish the same change with resistors exceeding the maximum limit of ree megohms. This circuit, which uses no sistors above one megohm, effectively offers same resistance as the one using 12 megohms.

As stated previously during the explanation network boxes, summing point J is at vir- ll ground. Therefore, the input circuit may redrawn (fig. 6-25), as a series-parallel circuit. The total resistance of this series-parallel circuit is found as follows:

$$R_t = R_1 + \frac{R_s \times R_2}{R_s + R_2}$$

$$R_t = 1.0 + \frac{(1.0)\ (.1)}{1.0 + .1}$$

$$R_t = 1.0 + .090909$$

$$Rt = 1.090909 \text{ megohms}$$

Knowing the value of R_t and the applied voltage, the total current in the single divider network can be determined:

$$I_t = \frac{E_{in}}{R_t}$$

$$I_t = \frac{12}{1{,}090{,}909 \text{ ohms}}$$

$$I_t = 11\ \mu\text{amps}$$

By knowing the total current through the single divider network it is possible to find

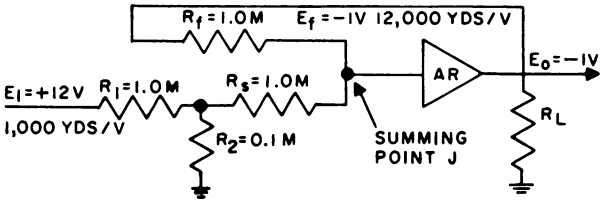

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Figure 6-24.—Circuit using a single divider network.

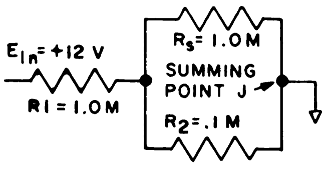

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Figure 6-25.—Input circuit redrawn as a series parallel circuit.

the voltage drop across each portion of the circuit. The voltage drop across R_1 is:

$E_1 = I_t X R1$

$E_1 = 11 \mu amps \ X \ 1.0 \ M$

$E_1 = 11$ volts

If 11 volts is dropped across R_1, then 1 volt must be felt across R_S and R_2. Thus, the current through each leg of the parallel circuit is:

$I_2 = \frac{E_2}{R_2}$ $\qquad I_S = \frac{E_S}{R_S}$

$I_2 = \frac{1 V}{0.1 M}$ $\qquad I_S = \frac{1 V}{1.0 M}$

$I_2 = 10 \mu amps$ $\qquad I_S = 1 \mu amp$

If only 1 μ amp of current is flowing through R_S, the same current is passing through the feedback resistor R_f. Therefore, $I_f = I_S$. Due to the single divider network in the input leg, an input voltage of +12 volts will cause an effective input voltage of +1 volt (which is across R_S) to be felt at summing point J. Therefore, the amplifier need only produce a -1 volt output to provide a zero or null condition at summing point J. Thus,

$I_f = I_S$

$\frac{E_f}{R_f} = \frac{E_S}{R_S}$

$E_f = R_f (E_S/R_S)$

$-E_f = 1(1/1)$

$E_f = -1$ volt.

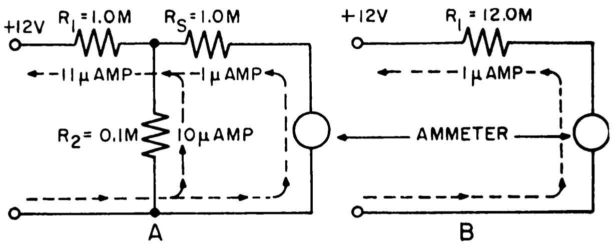

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Figure 6-26. —Similar resistor networks.

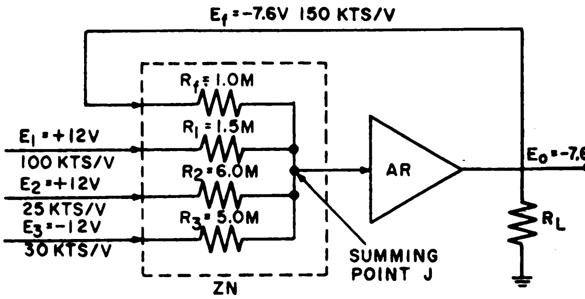

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Figure 6-27. —Circuit requiring two sing
divider networks.

The single divider network, (fig. 6-26A), whi
uses no resistors above one megohm, will pr
sent an effective resistance of 12 megohms
the input leg. This is the same as a 12-megoh
resistor would. See figure 6-26B. Thus, t
current through R_S is the same as if the in
leg consists of a 12-megohm resistor (1 μ a
in either circuit). The single divider netwo
does this because it is a voltage divider a
most of the current is passed through R_2 (1
amps) while only a very small portion (1 μ am
of the current is flowing through resistor R

A very useful formula to find the effecti
resistance of a single divider network is
follows:

Effective Resistance = $R_1 + R_S + \left(\frac{R_1 X R_S}{R_2} \right.$

Effective Resistance = $1.0 + 1.0 + \left(\frac{1.0 X 1.}{0.1} \right.$

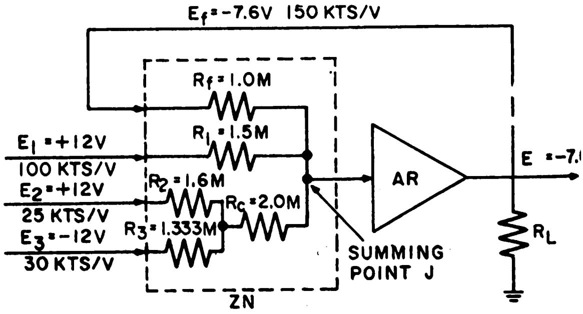

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Figure 6-28. —Circuit using a multiple divid
network.

Effective Resistance = 1.0 + 1.0 + 10.0

Effective Resistance = 12.0 megohms

When more than one single divider network is required in a summing computing loop, it is advantageous, if at all possible, to use a multiple divider network rather than two single divider networks. The summing computing loop illustrated in figure 6-27 requires two single divider networks because the resistance of two of the input legs is above three megohms.

Rather than use two single divider networks. one multiple divider network is used, as drawn in figure 6-28. In this network, resistor R_c is common to both the E_2 and E_3 input legs. The value of each resistor used in the input leg of E_2 and E_3 is selected so that the input circuit will deliver the same current to summing point J as the original circuit when the multiple divider network is supplied with the same input voltage.

The effective resistance formula is used to determine the effective resistance of input legs E_2 and E_3 so that the total current through R_c can be computed. Thus,

Effective resistance of E_2 leg:

$$R_{eff} = R_2 + R_c + \frac{R_2 \times R_c}{R_3}$$

$$R_{eff} = 1.6 + 2.0 + \frac{1.6 \times 2.0}{1.333}$$

$$R_{eff} = 6 \text{ megohms}$$

Effective resistance of E_3 leg:

$$R_{eff} = R_3 + R_c + \frac{R_3 \times R_c}{R_2}$$

$$R_{eff} = 1.333 + 2.0 + \frac{1.333 \times 2.0}{1.6}$$

$$R_{eff} = 5 \text{ megohms}$$

The current actually flowing through resistor R_c, is the difference between the currents resulting from the +12 volt and -12 volt inputs, or a total of .4 μ amps.

Current caused by +12V:

I_c = E/R, or 12/6.0 megohms = 2 μ amps

Current caused by -12V:

I_c = E/R, or 12/5.0 megohms = 2.4 μ amps

These two currents subtract; therefore a total of .4 μ amps will flow through resistor R_c to combine with the 7.6 μ amps through resistor R_f to provide the 8 μ amps required for resistor R_f.

The three inputs represent a total of 1,140 knots. Therefore, if the summing computing loop is functioning properly, the output voltage will represent 1,140 knots. Thus,

Input in knots:

12V X 100 Kts/V = 1,200 knots
12V X 25 Kts/V = 300 knots
-12V X 30 Kts/V = -360 knots
1,140 knots

Output in knots:

-8.0V X 150 Kts/V = 1,200 knots
-2.0V X 150 Kts/V = 300 knots
+2.4V X 150 Kts/V = -360 knots
-7.6V X 150 Kts/V = 1,140 knots

MULTIPLICATION AND DIVISION OPERATIONS IN ANALOG COMPUTERS

Multiplication and division operations in an analog computer are as important as summation operations. Multiplication may be performed electrically by amplifiers, and electromechanically by potentiometers. Multiplication and division in amplifiers was discussed previously and will not be covered here.

In an analog computer, the computer variables to be multiplied may be either voltages or motions (shaft rotations or positions). Therefore, multiplication of two variables may be performed by one of the following methods: volts x motion, motion x motion and volts x volts. Multiplication by each of these methods is discussed, and, where the same elements can be used for division, this operation is also covered.

MULTIPLICATION OF TWO VARIABLES WITH A POTENTIOMETER

In the discussion of potentiometers the pot was used to convert a mechanical computer variable into a corresponding electrical value. This was referred to as mechanical to electrical conversion. Actually, the pot multiplied a mechanical shaft position by a constant voltage; or in other words, a variable was multiplied by a constant.

The pot shown in figure 6-29 multiplies two computer variables, one electrical and the other mechanical; this demonstrates volts times motion multiplication. The potentiometer is energized by a voltage that can vary from -10 to +10 volts. This voltage represents a rate which is expressed in knots/volt. The mechanical input represents time in seconds, and can be varied from 0 seconds to 50 seconds at 5 seconds per turn of the 10 turn pot. The output represents a distance and is expressed in yards/volt. Thus, the potentiometer will perform any multiplication problem within limitations, involving Rate x Time = Distance.

Previously knots were converted to yards/second by the use of a constant, 0.563. The electrical scale factor, 2,815 yards/volt, includes the conversion of knots to yards/second, therefore the constant 0.563 is there but not seen. If a problem is computed mathematically however, the constant must be used.

The output scale factor can be determined by using the maximum input voltage and the two input scale factors. Thus:

Maximum input of knots is:

100 Kts/V x 10 volts = 1,000 knots

Maximum yards/second is:

1,000 knots x 0.563 = 563 Yds/Sec

Maximum yards/output is:

563 Yds/Sec x 50 seconds = 28,150 yards

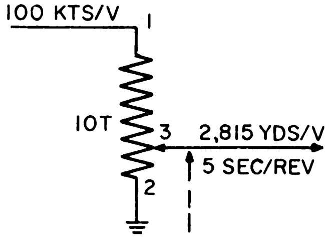

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Figure 6-29.—Potentiometer multiplication of two variables.

Output in yards/volt is:

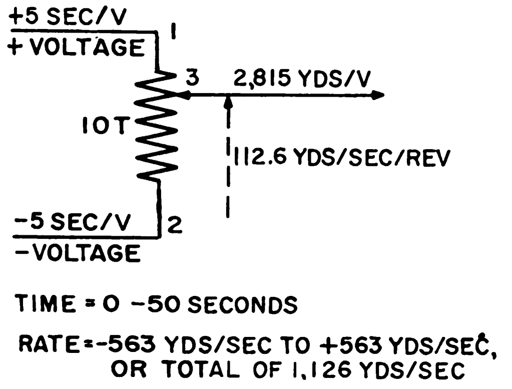
28,150 yards/10 volts = 2,815 Yds/V

If +6 volts were the input voltage and th slider were positioned to represent 20 seconds the output voltage would be 2.4 volts. This voltag represents 6,756 yards. Mathematically, this ca be proven as follows:

6 volts at 100 Kts/V = 600 knots
600 knots X 0.563 = 337.8 Yds/Sec
337.8 Yds/Sec X 20 Sec = 6,756 yards

Previously, in the study of pots, you saw tha for one position of the slider a certain outpu voltage was obtained because the input voltag was constant. However, when the input voltag is variable, many different output voltages ca be obtained for a given position of the slider. For example, several possible output voltages are listed below for the 20 second position o the slider, which is 0.4 of the total travel

Input	Output
1,000 knots = +10 Volts	10V X .4 = 4V or 11,260 yds.
800 knots = +8 Volts	8V X .4 = 3.2 V or 9,008 yds
600 knots = +6 Volts	6V X .4 = 2.4 V or 6,756 yds
400 knots = +4 Volts	4V X .4 = 1 .6 V or 4,504 yds
200 knots = +2 Volts	2V X .4 = 0.8 V or 2,252 yds
100 knots = +1 Volts	1V X .4 = 0.4 V or 1,126 yds
0 knots = 0 Volts	0V X .4 = 0.0 V or zero yds
-300 knots = -3 Volts	-3V X .4 = -1.2 V or 3,378 yds
-500 knots = -5 Volts	-5V X .4 = -2.0 V or 5,630 yds
-700 knots = -7 Volts	-7V X .4 = -2.8 V or 7,882 yds
-900 knots = -9 Volts	-9V X .4 = -3.6 V or 10,134 yds



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ıre' 6-30.—Double-ended potentiometer multiplication of two variables.

UBLE—ENDED POTENTIOMETER A MULTIPLIER

Previously, a double-ended potentiometer was ed to represent electrically a variable that uld be either plus or minus with respect a zero reference. Each end of the pot was ergized with a voltage—one end with a plus ltage, the other with a negative voltage. How- er, some analog computers also utilize a uble-ended pot to solve multiplication prob- ns similar to the one just studied.

Illustrated in figure 6-30 is a double-ended t which can do the same multiplication prob- m just discussed. Each end of the pot is ergized by a voltage which represents time. lus and minus voltages are used because the te can be either plus or minus with respect a zero reference. Therefore, a positive rate ill produce a plus voltage and a negative rate ill produce a minus voltage. The mechanical put represents the rate and is expressed in rds/second. The conversion from knots to rds/second has already been done. The zero sition of the slider is at the center of the tentiometer, as is the case for all double- ded potentiometers. Thus, from the center f the potentiometer to either end represents 53 yards/second, or a total of 1,126 yards/ cond. A 10-turn potentiometer is used, therefore e mechanical scale factor is 112.6 Yds/Sec/Rev. he slider movement from the center to either d of the potentiometer will represent 1,000 ots (563 Yds/Sec/.563).

If the same multiplication problem, +600 ots X 20 seconds = 6,756 yards were presented to the potentiometers, the following conditions would exist:

> ± 4 volts would energize the potentiometer thus representing 20 seconds (4 volts X 5 Sec/V = 20 seconds).
>
> To represent +600 knots, the slider is rotated 3 revolutions so that the slider moves upward from the center a total of 337.8 Yds/Sec (3 Rev X 112.6 Yds/Sec/Rev = 337.8 Yds/Sec, or 600 knots).
>
> The output voltage will be +2.4 volts (+4 volts X 2(3/10) = +2.4 volts).
>
> +2.4 volts, whose scale factor is 2,815 Yds/V, therefore represents 6,756 yards (2,815 Yds/V X 2.4 volts = 6,756 yards).

CASCADING POTENTIOMETERS FOR MULTIPLICATION

So far in our discussion of linear potentiometers we have assumed that the output is connected to a high impedance which does not draw any appreciable amount of current from the poten-

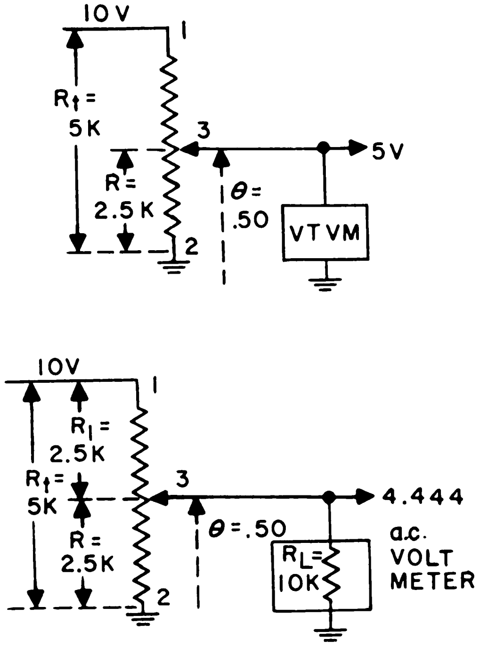

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Figure 6-31.—Loading effect of an a-c voltmeter.

tiometer. The output is therefore directly proportional to the angle of rotation of the potentiometer shaft multiplied by the input voltage or $E_o = E_{in} X\theta$. This equation may be rewritten as $E_o = E_{in} (R/R_t)$ if the potentiometer is labeled as shown in figure 6-31. Thus when the input is 10 volts and the slider is positioned at its center of travel, the open-circuit voltage at the slider is 5 volts if measured with a vacuum tube voltmeter. However, if an a-c voltmeter with an impedance of 1,000 ohms/volt is used to measure the output voltage, the meter will draw current and the output voltage will be reduced to 4.444 volts. This type of a-c voltmeter should not be used to measure the output voltage from a computing potentiometer. The output voltage was determined by first computing the effective resistance of the circuit using the formula for effective resistance. Be careful, make certain you understand which resistance of the parallel branch is acting as an effective total resistance. It may be to your advantage to review the method of calculating effective resistance.

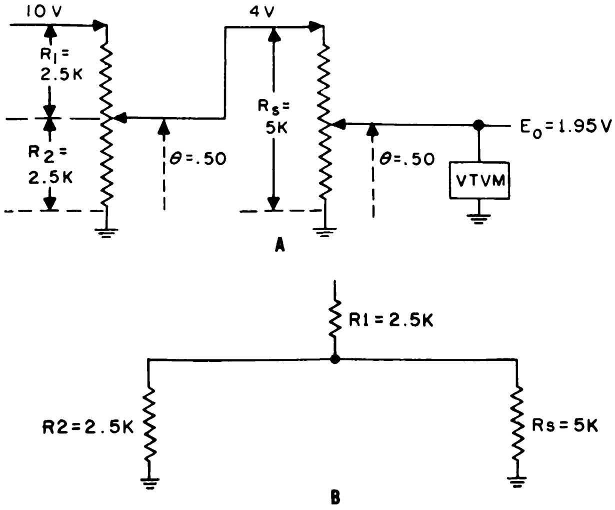

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Figure 6-32.—A. Loss of voltage due to loading a potentiometer, B. Series parallel circuit formed.

To obtain the electrical product of two mechanical variable, two pots may be used. This is referred to as motion x motion multiplication. However, if the pots are connected as shown in figure 6-32A, the second pot will draw current, thus loading the first pot. As a result, the output voltage of the first pot is not proportion to shaft rotation but is less than that value by a amount which depends on the current drain as wel as the position of the slider and its total resistance. Hence, the output of the second pc is in error even though the output is connecte to a high impedance load, because the potentiometers are connected so that a series parallel circuit is formed, as shown in part B o the figure.

The formula for computing the total effectiv resistance of the circuit can be used:

$$\text{Total } R_{eff} = R_1 + \text{Effective R of } R_s \text{ and } R_2$$

$$\text{Total } R_{eff} = R_1 + \frac{R_s + R_2}{R_s + R_2}$$

$$= 2.5K + \frac{12.5K}{7.5K}$$

$$= 2.5K + 1.6K$$

$$= 4.1K \text{ ohms}$$

This effective resistance of the circuit is the used to determine the voltage applied to th

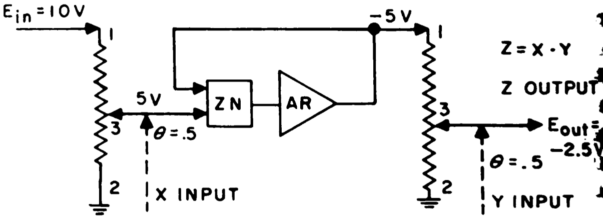

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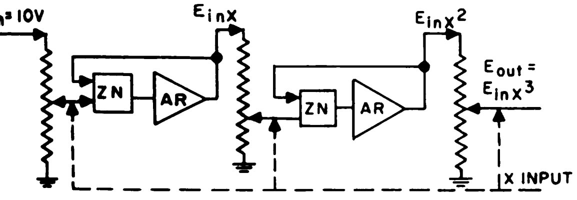
Figure 6-33.—Elimination of loading effect f accurate multiplication.

second potentiometer which can be found using the ratio:

$$\frac{\text{Input voltage}}{\text{Total effective resistance}} = \frac{\text{X(voltage applied to second p}}{\text{Effective resistance of } R_s +}$$

$$\frac{10 \text{ volts}}{4.1\text{K ohms}} = \frac{X}{1.6\text{K ohms}}$$



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gure 6-34.—Powers by successive multiplication.

$$(X)(4.1K) = 16K$$

$$X = 3.9 \text{ volts}$$

his 3.9 volts is applied to R_s, the slider of $_s$ is at its center of travel (50%). The voltge out (E_0) from R_s equals:

$$E_0 = E_{in} \times \theta$$

$$= 3.9 \times 0.5$$

$$= 1.95 \text{ volts}$$

To eliminate the error in the output due o loading, the two potentiometers are isolated rom each other with a network box and a feedack (isolation) amplifier, shown in figure 6-33. Vith the loading effect eliminated, the output s an accurate 2.5 volts. This is due to the act that R_2 is no longer in parallel with R_s, ut is in parallel with the input to the network box.

If the potentiometers are ganged together, s shown in figure 6-34, and the mechanical inut is designated as the X input, then the output is equal to $E_{in} X^3$. Thus, potentiometers may be used to raise the power of an input (X). f a fourth potentiometer is used, the variable is raised to the fourth power, and so on, by dding pots.

IVISION WITH POTENTIOMETERS

Potentiometers can be used to perform division as well as multiplication. When two potentiometers were used for multiplication, the output was taken from the slider of the second potentiometer. To perform division, the output from the slider is fed back as a nulling voltage

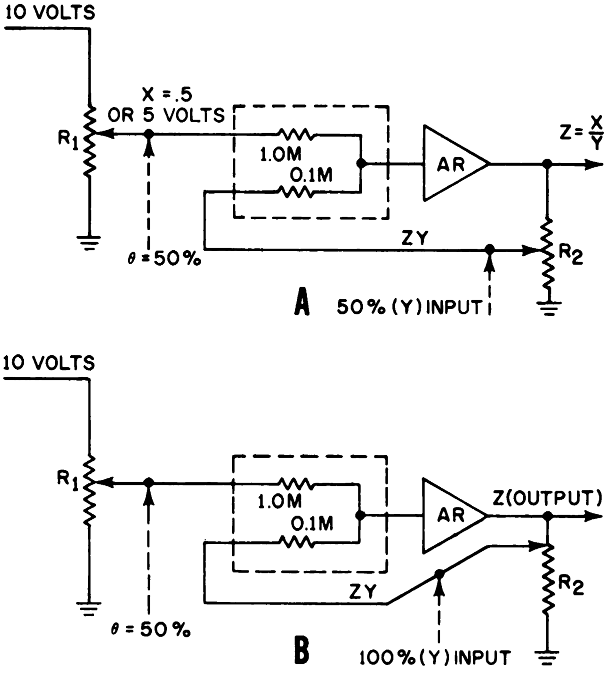

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Figure 6-35.—A. Divider loop using potentiometers; B. Divider loop operation.

to the network box. The equation solved is Z = X/Y.

There are two facts known about the elements in a divider loop; a potentiometer is a multiplier, and a two-legged network box has equal knowledge (not necessarilly equal voltage) on each leg. In addition to these two known facts for the loop to perform division, the input-output ratio of the amplifier must be variable.

Looking at figure 6-35A, there are two variables in the circuit. The first is the input voltage into the network box (X input), the second is the amount of voltage fed back to the network box (determined by the Y input). The output of the loop is unknown, and is called (Z). Potentiometer R_1 is supplied with a voltage, in this problem 10 volts. The slider is moved through an angle X = .5 or 50%, and the output from the slider is 5 volts. R_2 is supplied with the amplifier output (Z) and the slider is moved through an analog which is the Y input. Potentiometer R_2 actually multiplies the input voltage (Z) by the position of its slider (Y) and the output voltage (ZY) is the other input to the network box. As the output of the network box is theoretically zero; then

$$0 = X - ZY$$

or $$ZY = X$$

then $$Z = \frac{X}{Y}$$

Taking into consideration the ratio of the network box resistances, the output is:

$$Z = \left(\frac{R_f}{R_s}\right) \frac{\text{X voltage}}{\text{Y voltage}}$$

Due to the ratio (R_f/R_s) of the network box and the X input, only 0.5 volt is required to null the 5 volts input to the network box. This can be shown by moving the slider of the potentiometer R_2 to 100% of its travel; then the output of the amplifier is fed directly to the feedback leg of the network box, this is shown in figure 6-35B. The problem then becomes:

$$Z = \left(\frac{R_f}{R_s}\right) \frac{\text{X voltage}}{\text{Y voltage}}$$

$$= \frac{.1}{1} \times \frac{5}{1}$$

$$= 0.5 \text{ volt}$$

As long as the input remains 5 volts, the feedback voltage will be 0.5 volt, but the output of the amplifier will vary as the Y input is changed, picking off a portion of the amplifier output.

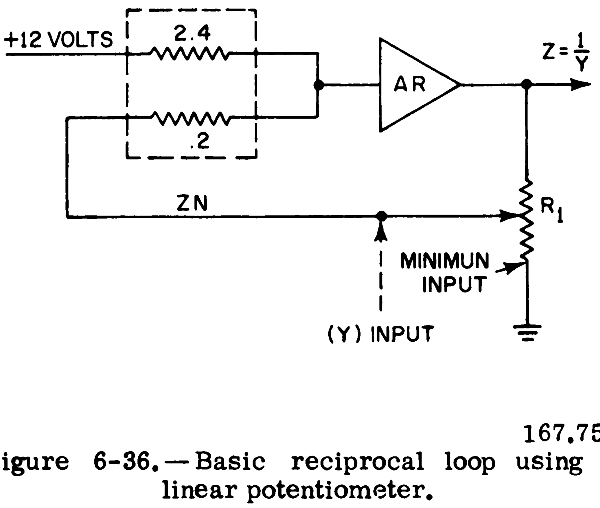

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Figure 6-36.—Basic reciprocal loop using a linear potentiometer.

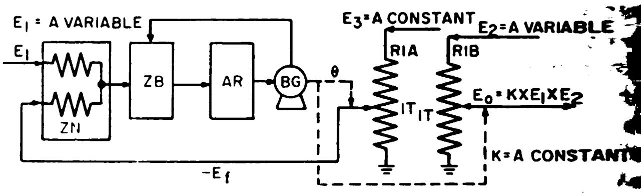

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Figure 6-37.—Volts X volts multiplication with a servo multiplier.

Therefore, the gain of the amplifier is variable depending on the position of the slider of R_2. However, if the 5 volts input is changed, the amount of feedback voltage required to null this change will vary accordingly. For example, if the X input voltage were changed to 8 volts (representing X = .8), the amount of feedback required to null this voltage would be .8 volt.

$$E_f = E_s \frac{R_f}{R_s}$$

$$= 8 \frac{.1}{1}$$

$$= .8$$

Taking the reciprocal of a quantity (fig. 6-36) is also a division process. In a reciprocal circuit, the input to the network box is a constant voltage (computer reference), and the slider of the pot is moved by the mechanical input Y. The voltage output of the amplifier is the electrical reciprocal of the mechanical input providing the slider is positioned at the top of the pot for maximum input, and near ground potential for minimum input.

SERVO MULTIPLIER

The servo multiplier is used to multiply two voltages together with the output as a voltage. The principle of operation is to first convert one of the voltages to a proportional mechanical displacement or rotation by using a servo. This mechanical quantity moves the slider of a ganged potentiometer to perform the final multiplication. A servo multiplier is illustrated in figure 6-37.

The two voltages to be multiplied are desigated E_1 and E_2. Each of these voltages repreents a computer variable. Through servo action, he servomotor positions the slider of potentiomter R1A so that the feedback voltage to the netork box is always proportional to the input oltage E_1. Bear in mind that the feedback oltage, E_f, can represent several input voltages o the network box. Because potentiometer R1A s linear, the output angle θ is proportional to he input voltage E_1.

Now, let us assign values to voltages E_1 and $_3$. Look at figure 6-37. If E_3 is a constant 12 volts and E_1 is +6 volts, the servo will drive ntil the slider of potentiometer R1A provides 6 volts of feedback to the network box. At this ime, the servomechanism stops driving and the lider of potentiometer R1A is at 50 percent of a full rotation. Since pots R1A and R1B are ganged ogether, the slider of R1B is also at 50 percent f a full rotation. Potentiometer R1A has provided the feedback voltage to position its slider correctly, and the multiplication will be performed by the potentiometer R1B.

If a value of 8 volts is assigned as the input voltage to potentiometer R1B, the output voltage of the servo multiplier can be determined. Two values concerning the potentiometer are known: first, the slider is positioned at 50 percent of full rotation, and secondly, the input voltage is 8 volts, thus, the equation, $E_O = E_2$ X percent of rotation can be used to find the output voltage. For this example E_O is 4 volts.

The output voltage can be computed mathematically by using the formula assigned to the output of potentiometer R1B. The formula is:

$$E_O = K \times E_1 \times E_2$$

The constant K will always be the reciprocal of the E_3 voltage applied to the feedback or nulling potentiometer R1A. The constant for this example is 1/12. Therefore $E_O = 1/12 \times 6 \times 8$, or 4 volts.

By assigning scale factors to the servo multiplier (fig. 6-38), any rate times time problem can be solved. The scale factors assigned below are for a target capable of traveling at a maximum speed of 810 knots. The computer reference voltage is 12 volts, and the maximum limit of time is 30 seconds. The problem is to convert a 6-volt input, with a scale factor of 2.5 seconds/volt, to a mechanical position and multiply this position by a rate expressed in yards/second/volt. The rate, 540 Kts is represented by the 8-volt input to potentiometer R1B, and has a scale factor of 38.0025 yards/second/volt. The output voltage will therefore represent yards (yards/second X seconds = yards).

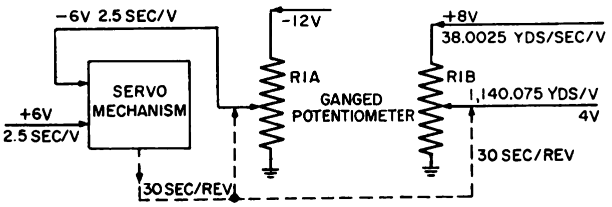

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Figure 6-38.—Servo multiplier with assigned scale factors.

The servomechanism will position itself so that potentiometer R1A provides -6 volts feedback to the network box to null the input signal of +6 volts. This position represents 15 seconds, and potentiometers R1A and R1B are positioned at 50 percent of a full rotation. 6V at 2.5 Sec/V = 15 Sec.

Potentiometer R1B will perform the multiplication of 15 seconds times 8 volts at 38.0025 yards/Sec/volt. The 8 volt (8 X 38.0025 = 304.02). Thus multiplying yards/second X seconds = yards (304.02 X 15 = 4,560.3). The results can be checked by dividing the yardage by the electrical scale factor of the output voltage. Thus,

$$\frac{4,560.3 \text{ yards}}{1,140.075 \text{ Yds/V}} = 4 \text{ volts.}$$

TRIGONOMETRIC FUNCTIONS IN ANALOG COMPUTERS

In electrical analog computers, a-c resolvers are used primarily for the solution of right triangles and coordinate rotation. In the solution of a particular problem in a computer, the resolver must be used in conjunction with a network box and feedback amplifier. In many cases, the output of a resolver will be the input to other resolvers, until as many as six or seven are connected into a resolver chain. As you learned in chapter 5, resolvers are low impedance elements. Therefore to compute accurately they must be isolated from the preceding element to prevent loading. Isolation is provided by a network box and feedback amplifier. The amplifier is sometimes called an isolation or booster amplifier. It has a low output impedance and can correct any undesirable phase shift developed in the resolver. Thus, in actual application,

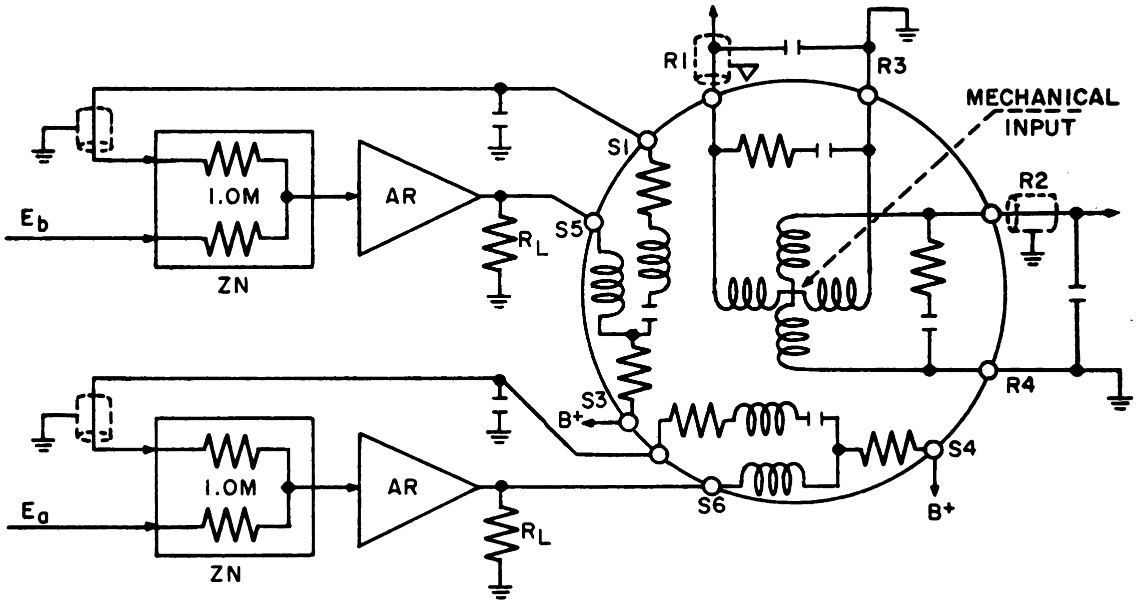

Figure 6-39.—Basic resolver loop.

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resolvers are connected in what may be referred to as basic resolver loops.

BASIC RESOLVER LOOP

Figure 6-39 shows a circuit diagram of a basic resolver loop. The input voltages are designated as E_a and E_b. The voltages are in phase or 180° out of phase with the computer reference voltage. The input voltages are always impressed on the stator windings of a resolver via a network box and isolation amplifier. Signal flow in the stator circuit is somewhat different than that of a sign reversing or summing computing loop. In those loops, the amplifier output was fed directly back to the network box as the feedback voltage. However, in a resolver loop the output of the amplifier excites the stator winding of the resolver, which induces a voltage in an additional winding called the feedback winding. The voltage induced in the feedback winding is fed back to the network box as the feedback voltage, which must be out of phase with the input voltage to the network box.

The magnitude of the amplifier output is less than the input voltage to the network box, and a slight phase shift is designed into the loop to compensate for the phase shift developed in the resolver. There is a slight step-up of voltage between stator and rotor so that unity gain is achieved between the input of the loop (at the network box) and the output. In addition, to help achieve the unity gain desired and resolver interchangeability, the feedback and output leads are trimmed with a capacitor to provide a constant value of capacitance (up to 2,000 μμfd in some computers). These leads are coaxial cables and naturally have a certain capacitance per foot; therefore, trimming is necessary so that the various lengths of cables are made uniform in capacitance. The shields of the coaxial leads are grounded.

The amplifier output is also connected to a load resistor for proper operation of the amplifier. The load resistor may be mounted within the network box or mounted externally.

When the voltage at Eb is zero and the Ea voltage is of some nominal magnitude, the voltage induced in the R1-R3 winding will be equal to the Ea voltage and of the same phase, providing the rotor is at its zero position. At this zero position of the rotor, zero volts will be induced in the R2-R4 winding.

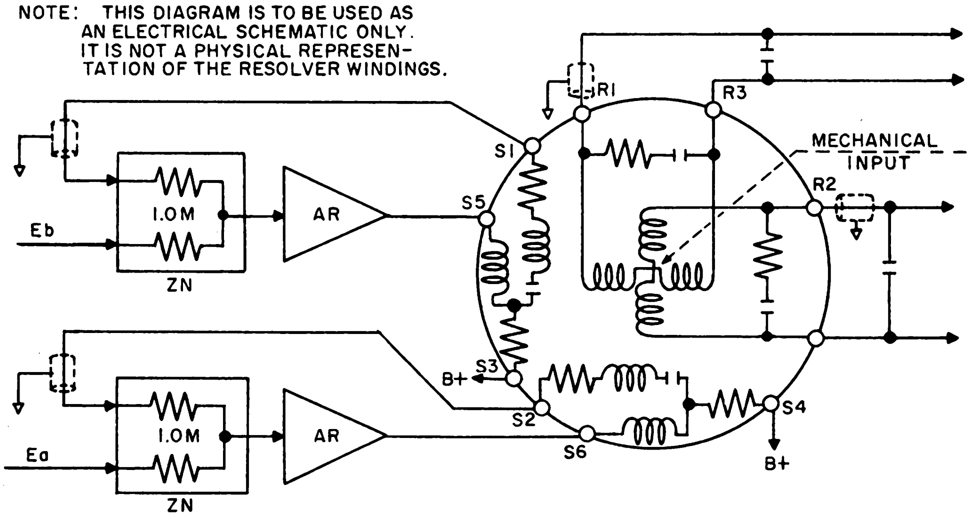
Clockwise rotation of the rotor will cause a voltage to be induced in the R2 winding that is out of phase with the Ea voltage. Counterclockwise rotation of the rotor will cause a voltage to be induced in the R2 winding that is in phase with the Ea voltage. When the rotor is at a position so that these conditions are met, the resolver is said to be on electrical zero.

Once the electrical zero position of a resolver has been set, problems involving resolution, composition and coordinate rotation can be solved by the resolver. To solve problems, the voltages induced in the rotor windings follow an established equation depending on the polarity of the Ea and Eb inputs, the rotor lead selected, and the direction of rotation of the rotor. For example, assume that Ea and Eb are +8 volts, and the rotor is rotated 30° clockwise. The voltages induced in rotor leads R1 and R2 are as follows: (Negative values determined by phase comparison.)

$$\begin{aligned} R1 &= EaCos\ 30° + EbSin\ 30° \\ &\quad 8(.866) + 8(.5) \\ &\quad 6.928 + 4 \\ &\quad 10.928 \text{ volts} \end{aligned}$$

$$\begin{aligned} R2 &= EaSin\ 30° + EbCos\ 30° \\ &\quad -8(.5) + 8(.866) \\ &\quad -4 + 6.928 \\ &\quad + 2.928 \text{ volts} \end{aligned}$$

For the same Ea and Eb inputs, rotation of the rotor counterclockwise a total of 30° will


NOTE: THIS DIAGRAM IS TO BE USED AS AN ELECTRICAL SCHEMATIC ONLY. IT IS NOT A PHYSICAL REPRESENTATION OF THE RESOLVER WINDINGS.

	HIGH	LOW SIDE	ROTATION	OUTPUT FUNCTIONS			
				+Ea +Eb	+Ea -Eb	-Ea -Eb	-Ea + Eb
1	R1	R3	CW	EaCosθ+EbSinθ	EaCosθ-EbSinθ	-EaCosθ-EbSinθ	-EaCosθ+EbSinθ
2	R3	R1	CW	-EaCosθ-EbSinθ	-EaCosθ+EbSinθ	EaCosθ+EbSinθ	EaCosθ-EbSinθ
3	R2	R4	CW	-EaSinθ+EbCosθ	-EaSinθ-EbCosθ	EaSinθ-EbCosθ	EaSinθ+EbCosθ
4	R4	R2	CW	EaSinθ-EbCosθ	EaSinθ+EbCosθ	-EaSinθ+EbCosθ	-EaSinθ-EbCosθ
5	R1	R3	CCW	EaCosθ-EbSinθ	EaCosθ+EbSinθ	-EaCosθ+EbSinθ	-EaCosθ-EbSinθ
6	R3	R1	CCW	-EaCosθ+EbSinθ	-EaCosθ-EbSinθ	EaCosθ-EbSinθ	EaCosθ+EbSinθ
7	R2	R4	CCW	EaSinθ+EbCosθ	EaSinθ-EbCosθ	-EaSinθ-EbCosθ	-EaSinθ+EbCosθ
8	R4	R2	CCW	-EaSinθ-EbCosθ	-EaSinθ+EbCosθ	EaSinθ+EbCosθ	EaSinθ-EbCosθ

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Figure 6-40. — Standards for resolver Mk 4 Mod 3.

cause different voltages to be induced in R1 and R2. The voltages induced are as follows:

$$\begin{aligned} R1 &= EaCos\ 30° - EbSin\ 30° \\ &\quad 8(.866) - 8(.5) \\ &\quad 6.928 - 4 \\ &\quad +\ 2.928 \text{ volts} \end{aligned}$$

$$\begin{aligned} R2 &= EaSin\ 30° + EbCos\ 30° \\ &\quad 8(.5) + 8(.866) \\ &\quad 4 + 6.928 \\ &\quad +\ 10.928 \text{ volts} \end{aligned}$$

Compare these voltages with those obtained when the rotor was rotated clockwise:

ROTATION OF ROTOR	R1 OUTPUT	R2 OUTPUT
CW	+10.928 V	+ 2.928 V
CCW	+ 2.928 V	+10.928 V

From the preceding comparison, it can be seen that the direction of rotation of the rotor has a very important bearing on the output voltages obtained. The preceding problems used a plus value of Ea and Eb. If either or both were negative, the outputs would naturally change.

The table in figure 6-40 shows the various combinations of output voltages available from a resolver under different conditions. The second and third column indicate the condition of the rotor connections: HIGH meaning the output lead, LOW SIDE meaning the rotor lead is grounded. The next column shows the direction of the rotor from electrical zero. The next four columns show the output function in relation to the polarity of the Ea and Eb inputs.

To illustrate use of the table, consider the preceding example where the rotor was rotated counterclockwise. Both Ea and Eb were positive and the R1 and R2 windings were the outputs. Under the HIGH column, locate the two lines where R1 is high (lines 1 and 5). The ROTATION column is used next to determine which of the two lines to use. In this case, since the rotor was turned counterclockwise, use line 5. To read the output function from the R1 rotor lead, locate the OUTPUT FUNCTION listed in the +Ea +Eb column. This reads: Ea Cos θ - Eb Sin θ, which is the same output function used to compute the R1 voltage in the preceding example.

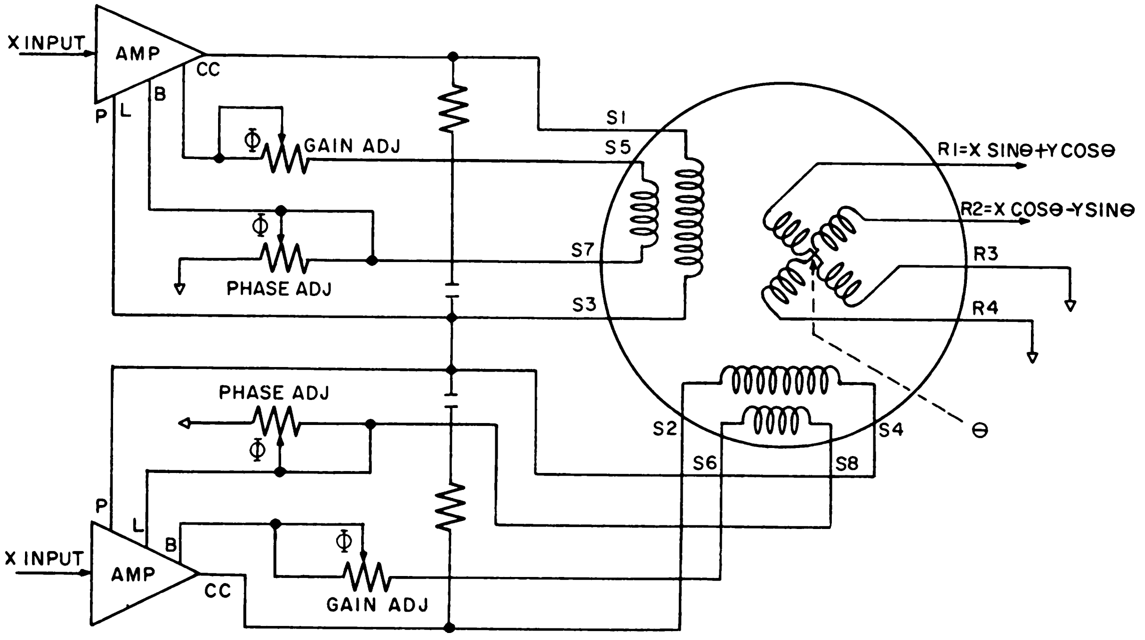

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Figure 6-41.— Basic resolver loop-practical application.

The OUTPUT FUNCTION of the R2 winding would be read on line 7 under the same output function column. This line reads: Ea Sin θ + Eb Cos θ, which is the same output function used in the original example.

When only one stator is energized, the input voltage will be applied as the Ea input. Therefore, only the Ea side of the equation is used; the Eb portion is deleted.

BASIC RESOLVER LOOP (practical application)

The basic equations for resolvers used in this example (fig. 6-41) are:

$$R1 = X \sin\theta + Y \cos\theta$$

$$R2 = X \cos\theta - Y \sin\theta$$

The outputs are not the actual phase of the output voltage, but merely indicate that the induced voltages will add or subtract when the rotor is in the first quadrant. To produce the above equations, stator windings S1 and S2 are supplied with a positive voltage (positive with respect to ground at the resolver, not the input to the amplifier), and the resolver rotor is rotated clockwise for an increasing quantity. Notice how the rotor is rotated in relation to the stator windings. This will be helpful when you actually phase out a resolver loop. When a resolver is replaced, the loop must be adjusted to provide unity gain between the input to the loop and the output. Two adjustments are involved: the phase and the gain adjustments.

The basic objective is to adjust the loop so that the output voltage of the rotor has the same phase and amplitude as the input voltage to the amplifier when the rotor is at its zero position.

At the zero position of the rotor, the winding concerned is parallel to the stator winding that is inducing the voltage in it. In this position, there should be unity gain, or one-to-one transformation, between the input to the amplifier, and the resolver output and a zero phase shift should take place. If unity gain or the desired phase shift is not achieved, then the phase and gain adjustments must be made so that the amplifier output is changed in both phase and magnitude to provide the proper output from the resolver.

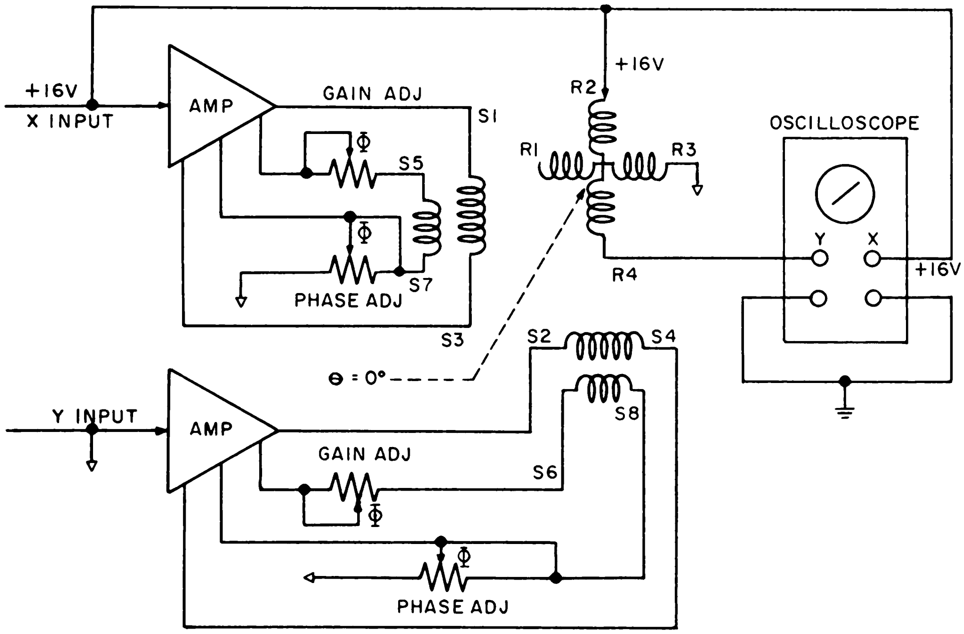

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Figure 6-42.—Oscilloscope connections for adjusting phase and gain of a resolver loop.

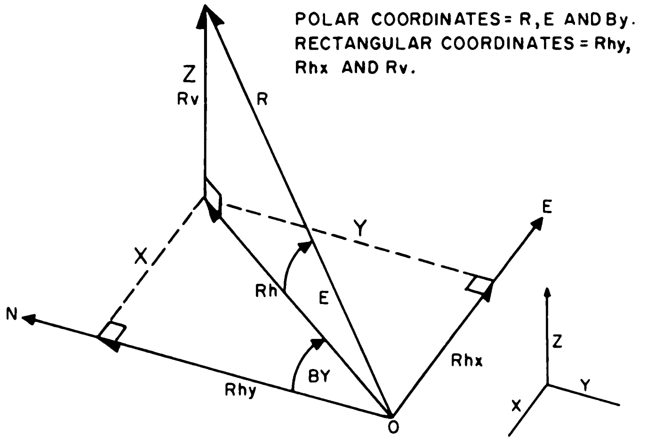
POLAR COORDINATES = R, E AND By.
RECTANGULAR COORDINATES = Rhy, Rhx AND Rv.
Z
Rv
R
X
Y
E
N
Rh
E
BY
Rhy
Rhx
O
Z
Y
X

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Figure 6-43.—Defining the position of a point in space by rectangular and polar coordinate systems.

Figure 6-42 illustrates the connections for making the gain and phase adjustments for the X input. The Y input is grounded, and all grounds shown must be common. The Lissajous pattern on the oscilloscope should make a diagonal figure eight, compressed in height as much as possible.

RESOLUTION

One of the trigonometric functions a resolver is capable of handling is the resolution of a vector. This is the process of taking a vector in its polar form and resolving it into its two rectangular components. To accomplish resolution with a resolver, one electrical input and one mechanical input are required. Two electrical outputs will be obtained.

Two resolvers can be used to resolve present target position (a vector in polar form) into three voltages representing target position in Cartesian (rectangular) coordinates. Figure 6-43 shows the geometry of the problem and figure 6-44 is a schematic diagram of a typical resolver chain that changes (transforms) polar coordinates into rectangular coordinates.

The electrical input to resolver BR-1 is range R. The rotor is mechanically positioned by target elevation E. The output from rotor lead R4 is target height Rv or the Z axis of a rectangular coordinate system. This is one of the electrical quantities desired. The output obtained from rotor lead R3 is horizontal range Rh. Thus the rectangular components (Rh and Rv) of the vector represented by R (its magnitude) and E (its direction) have been determined.

Horizontal range Rh (it can be thought of as the length of a new vector lying in the horizontal plane) is the electrical input to resolver BR-2. The rotor is mechanically positioned by true target bearing By (the direction of vector Rh). The output from rotor lead R3 is north-south horizontal range, Rhy or the Y axis of a rectangular coordinate system. The output from rotor lead R4 is eastwest horizontal range Rhx (the X axis). The outputs are the two quantities (X and Y) required to express present target position in Cartesian coordinates.

Resolver BR-1 solves the following equations: R CosE = Rh and R SinE = Rv. Resolver BR-2 solves the following equations: Rh CosBy = Rhy and Rh SinBy = Rhx.

COMPOSITION

Another trigonometric function a resolver handles is the composition of a vector. This is the process of taking a vector in its rectangular form and composing the vector in its polar form. In other words, two sides of a right triangle are known and the resolver solves for

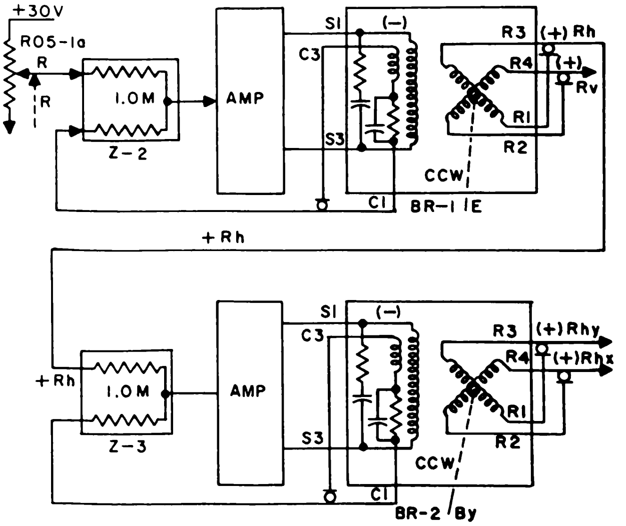

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Figure 6-44.—Typical resolver chain for converting polar coordinates into rectangular (cartesian) coordinates.

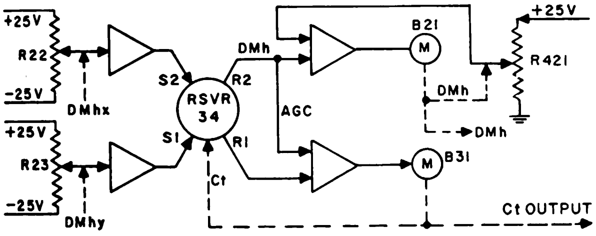

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Figure 6-45.—Vector composition.

the hypotenuse and acute angle. To accomplish composition with a resolver, both stator windings are energized. These inputs represent the height and base of the triangle. One electrical output and one mechanical output will be obtained. These outputs represent the hypotenuse and acute angle. To obtain a mechanical output from a resolver, one rotor winding provides the input signal to a servomechanism which drives the rotor of the resolver until zero volts is induced in the winding. When this operation is complete the resolver loop has composed the vector. The position of the rotor represents the angle of the vector and the other rotor output represents its magnitude.

The loop diagrammed in figure 6-45 is used to change rectangular coordinates of target motion to a vector quantity, thus representing target course (direction) and speed (magnitude). The two motion coordinates, DMhy and DMhx, are computed with respect to the N-S and the E-W axis, respectively. A resolver is used to compose these coordinates into a vector which has target course Ct as its direction and target speed DMh as its magnitude. Figure 6-46 shows the geometry of the problem.

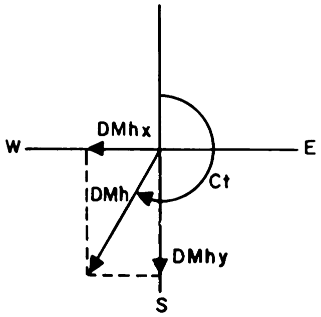

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Figure 6-46.—Geometry of rectangular to polar transformation (the composition of vector components).

Returning to fig. 6-45, potentiometers R22 and R23 are energized with +25 and -25 volts, since target rates (DMhx and DMhy) will be either plus or minus quantities. A target course of zero degrees is computed when the output of R22 is zero volts and R23 has a negative output.

To compute a target course of 45°, assume that the output of potentiometers R22 and R23 is -15 volts. Servomotor B31 will drive the rotor of resolver 34 counterclockwise until a null voltage is induced in the R1 winding. Concurrently, the voltage induced in the R2 winding will be a maximum negative voltage, or -21.21 volts.

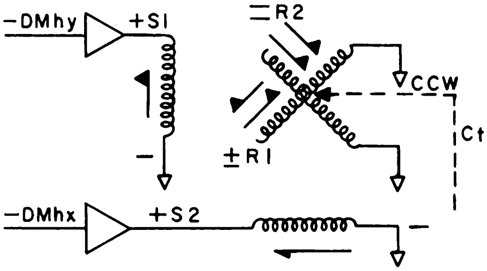

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Figure 6-47.—Polarity of rotor windings (R1 and R2) of B34.

To provide the above outputs, the voltages induced in R1 and R2 must follow an established equation in each rotor winding. These equations are:

$$R1 = -DMhx(\cos Ct) + DMhy(\sin Ct)$$

$$R2 = -DMhx(\sin Ct) - DMhy(\cos Ct)$$

The voltages induced in R1 (fig. 6-47) will subtract; therefore, the mechanical position of the rotor represents the angle of the target course vector. The voltages induced in R2 will add; therefore, the magnitude of the R2 voltage represents target speed DMh. A servomechanism

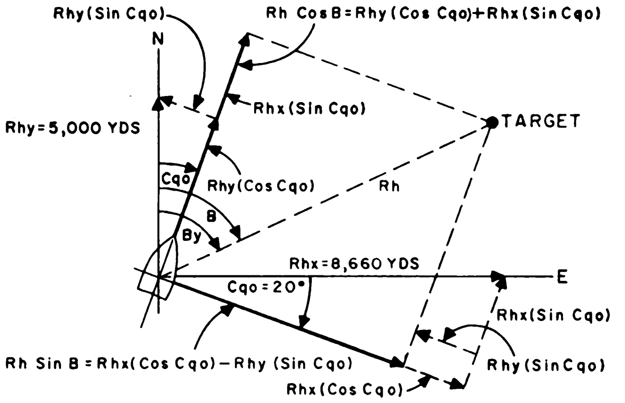

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Figure 6-48.—Geometry of a coordinate rotation problem.

is used to obtain a mechanical representation of target speed. Automatic gain control is provided to the Ct servomechanism so that the gain of the amplifier varies inversely with the target speed.

Another trigonometric function a resolver can handle is the rotation of coordinates. This process involves the rotation of rectangular coordinates from one axis system to another axis system.

To rotate coordinates from one axis system to another, a resolver must have one mechanical input and two electrical inputs. Two electrical outputs are obtained.

The geometry of a coordinate rotation problem is illustrated in figure 6-48. Target position is expressed by rectangular coordinates Rhx and Rhy. These quantities relate how far the target is from own ship, measured along the N-S and E-W axis. The problem is to express target position in rectangular coordinates with respect to the centerline of own ship; or in other words, to determine the distance to the target along and perpendicular to own-ship centerline. Actually, the quantities desired are the rectangular coordinates of the relative target bearing vector. The quantities Rhx, Rhy, and Cqo are given in figure 6-48.

To solve the two equations, Rh CosB=Rhy (CosCqo) + Rhx(SinCqo) and Rh SinB=Rhx(Cos Cqo) - Rhy(SinCqo), two resolvers are used. (See figure 6-49.) Horizontal range Rh and true target bearing By are the inputs to resolver B1 which resolve the polar vector into rectangular coordinates, Rhx and Rhy. The equations solved by resolver B1 are: Rhx = Rh SinBy and Rhy = Rh CosBy. The magnitude of Rhx and Rhy are +8.66V and +5V, respectively.

The rotor of resolver B2 is rotated by ships heading Cqo, and the stators are energized by Rhx and Rhy—stator S5 by Rhx and S6 by Rhy. If ship heading were 0°, resolver B2 would compute the rectangular coordinates of the polar vector; that is, the R1 output would be +5 volts and the R2 output would be +8.66 volts. However, ship's heading is 20°; therefore the R1 output will increase while the R2 output will decrease. The equations solved by resolver B2 are:

$$\begin{aligned} R1 = {} & Rhy(CosCqo) + Rhx(SinCqo) \\ & 5V(.9397) + 8.66V(.342) \\ & 4.70V + 2.96V \\ & + 7.66V \end{aligned}$$

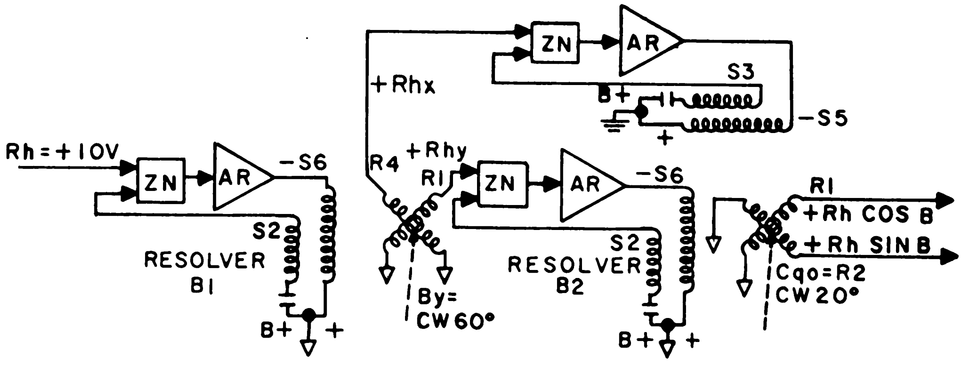

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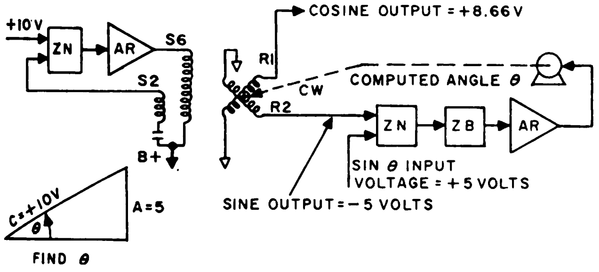
Figure 6-49.—Rotation of rectangular coordinates with resolvers.



167.109
Figure 6-50.—Inverse sine resolver loop.

$$\begin{aligned} R2 &= Rhx(CosCqo) - Rhy(SinCqo) \\ &\quad 8.66V(.9397) - 5V(.342) \\ &\quad 8.14V - 1.71V \\ &\quad + 6.43V \end{aligned}$$

The R1 and R2 voltages are the rectangular coordinates of the relative target bearing vector Rh and B, and are measured along and perpendicular to own-ship centerline. Hence the R1 voltage represents Rh CosB, and the R2 voltage represents Rh SinB.

INVERSE SINE AND COSINE LOOPS

A resolver can be used in a loop to solve for an angle, given the sine or cosine of that angle. Such a loop is shown in figure 6-50, and consists of a resolver, a network box, and a servomechanism.

In this loop the rotor of the resolver is driven by the servomechanism whose mechanical output is the computed angle θ. If the R2 voltage is not equal and of opposite phase to the Sin θ input voltage, a signal to the servomechanism will cause it to drive the rotor until it becomes equal.

Since the resolver stator is supplied with a constant voltage, the R2 voltage is at all times proportional to the sine of the computed angle; that is, R2 = 10V X sine of the computed angle. The R1 voltage is at all times proportional to the cosine of the computed angle; that is, R1 = 10V X cosine of the computed angle.

In other words, the resolver loop solves for angle θ when the hypotenuse (10 volts) and the height (Sin θ input voltage) are known. Assume that the Sinθ input voltage is +5 volts and that the resolver is energized by a constant +10 volts. The servomechanism will drive the rotor until the output of R2 is -5 volts, at which time the loop will stop driving. The resolver rotor must be rotated clockwise through a 30° angle to produce this output. The R1 output at this position of the rotor is +8.66 volts. If the Sinθ input voltage were changed to 3.42 volts, the resolver would solve a 20° angle. If the Sin θ input voltage were +8.192 volts, the resolver would solve a 55° angle.

The resolver loop can be made to function as an inverse cosine loop by selecting the rotor lead R1 as the input to the network box. By necessity, the other input to the network box would have to be a voltage that represents the cosine of the angle desired. The inverse cosine loop is shown in figure 6-51. Operation of the loop is the same as that discussed for the inverse sine loop, except the two known parts of the triangle to be solved are now the hypotenuse and adjacent side.

If the Cos θ input voltage were -8.66 volts, the resolver loop would solve a 30° angle. The R2 output voltage would be -5 volts. If the Cos θ input voltage were -9.397 volts, the resolver loop would solve a 20° angle, and the R2 output would solve a 50° angle, and the R2 output would be -7.660 volts.

Note that only one stator winding of the resolver was energized in either loop. Thus, the hypotenuse of the triangle was represented by the input voltage to the resolver.

RATE COMPUTING LOOPS OF ANALOG COMPUTERS

In an analog computer, a rate computing loop establishes the rate of change of its input, and compares the output against the input, thereby determining the acceleration or deceleration of the input. The mathematical process of obtaining the rate of change of a quantity is known as differentiation, and the result is the derivative. In an analog computer, the process is referred

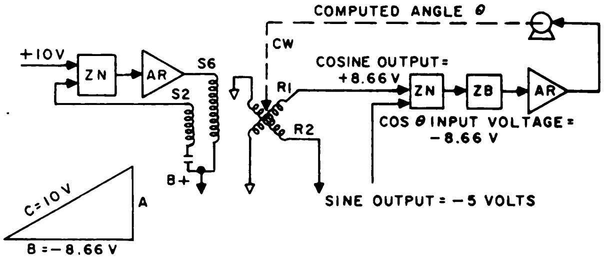


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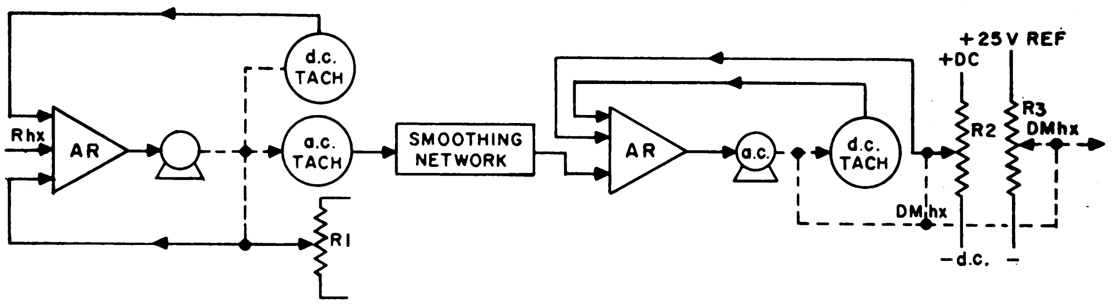
Figure 6-51.—Inverse cosine resolver loop.



167.111

Figure 6-52.—DMhx rate loop.

to as rate control; that is, when an error exists between the input and the established rate, the loop will correct the rate. In an analog computer using the Cartesian coordinate system, the rate of change of Rhx, Rhy, and Rv are determined so that the future target position can be predicted. The rate of change in Rhx, Rhy, and Rv are DMhx, DMhy, and DMv, respectively. Figure 6-52 shows a typical rate computing loop consisting of an a-c servo, a d-c tachometer, and a d-c servo. The loop establishes the rate of change of position of a target along the east-west coordinate. Or in fire control shorthand, the overall loop establishes DMhx. East-west horizontal range (Rhx) is the input to the a-c servoloop which converts the input voltage to an equivalent shaft rotation. The a-c servo output rotates the rotor of a d-c tachometer, which generates a d-c voltage proportional to the rate of change of Rhx. This signal is passed through a smoothing network where any sudden changes in the d-c level are filtered out. The smoothed d-c voltage is then fed to the d-c servo, which positions the slider of potentiometer R2. The voltage picked off the slider of R2 is fed back to cancel the d-c input signal. When these two voltages are equal in amplitude and opposite in polarity, the servo stops driving. At this time (null) the position of the servo represents the linear rate—DMhx. Potentiometer R3 simply converts the mechanical position of DMhx into an a-c signal for use in another section of the computer.

Since the target is constantly in motion, the Rhx input voltage will be changing. If the target maintains a steady course and speed or constant velocity, the Rhx voltage will change at a linear rate. The output of the d-c tach in the a-c servoloop will represent this linear rate by producing a constant d-c voltage. So once the d-c servo has established DMhx, the servo will not move until there is an increase or decrease in the rate at which the Rhx input is changing. This change will occur only when the target increases or decreases speed or changes course, or in other words, the target accelerates. When there is an increase or decrease in the rate at which the Rhx input voltage changes, the tachometer output will vary accordingly. The two d-c inputs to the d-c servo now have different amplitudes, and the servo drives to establish a new DMhx and provide a feedback voltage to cancel the tachometer voltage.

SUMMARY

The fundamental characteristic of an analog is similarity to the subject in some area; i.e., it duplicates the geometry, dynamic behavior, or some other aspect of the subject. The basic operating principle of an analog computer is continuous measurement of quantities.

Analog computers can be employed in weapons and fire control systems wherever problems of calculations from continuous data, simulation, or control are encountered.

This continuous calculation requires that the fire control computer be designed for a particular system, which reduces its versatility. Fire control computers are not general purpose computers. Several quantities are continuously measured in the fire control system (such as range, bearing and elevation of the target) and always applied to the same inputs of the analog computer. Inside the computer, the manipulations are continuously performed and the results are continuously available at the outputs, to be fed to the rest of the fire control system.

In the areas of target detection and tracking, analog computers are used to direct search radars and tracking/guidance radars, store data on target location and velocity, and predict future target motion. The calculations necessary to direct guided missile launchers, and actually control launchers and missiles are performed by computers. In addition to actual operation of fire control systems, analog computers are used to simulate targets for training purposes, and evaluate the performance of fire control systems in engaging the simulated targets. The history of increasing complexity in fire control systems and the increasingly rapid pace of warfare, as well as improvements in the capabilities of computers, indicate a still greater dependence on computers in the future.

CHAPTER 7

FUNDAMENTALS OF DIGITAL COMPUTERS

Digital computers and other equipment based on digital techniques are becoming increasingly common in missile fire control system. Furthermore, those ships having 3D radars employ digital data processors. Looking at today's developments in the fire control field, we see more and more applications for digital computers, as well as a trend toward their replacing many of today's analog computers. Consequently, fire control technicians will find a collection of electronic systems which use digital equipment as integral parts of the overall weapon control system. In order to understand the operation of the total system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology, and applications. Basic Electronics, NavPers 10087-C, Digital Computer Basics, NavPers 10088A, and Mathematics, Vol. 3, NavPers 10073-A, present a basic coverage of the purpose, operation, and theory of computers, together with terminology peculiar to them. Review and study of these will aid in understanding this chapter.

INTRODUCTION TO DIGITAL COMPUTERS

A computer is any device capable of accepting information, applying mathematical operations to that information, and obtaining results of these operations. Therefore, a computer must have an input, processing, and output section.

Before any problem can be solved by a computer, the quantities involved must be expressed in terms of common units; that is, digital computation is the process in which digits alone are used to solve the problem.

Basically, the purpose of a digital computer is the same as that of any other computational aid. However, it is more accurate within practical limits of speed. Computers can perform thousands of repetitive computations involvin hundreds of thousands of digits without makin an error. Further, they can store millions o items of information for future use.

Digital computers also have limitations i that a continuous variable cannot be processed Simple and explicit instructions (programming must be provided for each operation that is t be performed. Instructions as to where information is stored, how to use it, what to do wit it, and what step is required next are sometimes more complicated than the problems fo which the computer is used to solve. Approximations and rounding off are also problem encountered with computers.

A digital computer performs its calculation by counting and comparing. With this simpl capability, it can add, subtract, multiply, divide and make logical decisions. Therefore, to perform computations with a digital computer, all tha is needed is a method which will enable th machine to count, compare, and transfer digit from one place to another. To understan the operation of computer devices, it is necessary to learn the language of the computers

NUMBERING SYSTEMS

While there are many different numberin systems, this discussion will deal with three the base ten (decimal), base two (binary) an base eight (octal) systems. The binary system will be compared with the decimal system because all computers utilize the binary system Following this comparison, we will examine th octal system in relation to the decimal and binar systems. The bistable nature of simple electronic components (such as switches, open an closed, and tubes and transistors — conducting o cutoff) makes the binary numbering system convenient tool.

In the decimal system ten digits are use (0 through 9), and in the binary system tw digits are used (0 and 1). The symbols or digits used are repeated as many times as desired or needed. Both systems also use the place value of positional notation concept. This means that a numeral has a specific value of its position.

POSITIONAL NOTATION

An example of place value is shown in the two numbers 230 and 203. The 3 has a different value in each number by virtue of its position.

In this example, when the number 230 is expressed as two hundred thirty, some assumptions are made which must be understood in order to compare the decimal and binary systems.

The first assumption the reader makes upon looking at the number 230 is that the number is a decimal number. When no base symbol is given, the decimal system is assumed. If the number had been a base four number, it would have been written as $230_{(4)}$ with the 4 indicating the base of the numbering system. Some examples and their numbering base symbols are as follows:

Number	Base
398	ten (decimal)
$342_{(5)}$	five (quinary)
$101_{(2)}$	two (binary)

When a number is written in base ten, no base indicator is given. If the number is written in a base other than ten, the base indicator is used.

Another assumption made is that the number 230 is two hundred thirty; that is, the digit 2 indicates hundreds, the digit 3 indicates tens, and the digit 0 indicates units. In base ten this is true. The digits have specific values according to their position. Place value or positional notation for the number 378924 in the decimal system is as follows:

Place value	10^5	10^4	10^3	10^2	10^1	10^0
	100000	10000	1000	100	10	1
Number	3	7	8	9	2	4

Notice that the place value column on the right is 10^0 or 1. The increasing place values, moving to the left, are indicated by the base (10) raised to one greater power. The second place value column is, then, 10^1, the third is 10^2, etc.

The number 378924, then, is 3(100000) + 7(10000) + 8(1000) + 9(100) + 2(10) + 4(1).

The place value columns for binary (base two) system follow the same pattern as the base ten system except the base two is used. For example, the number $10110_{(2)}$ is indicated in the place value chart for base two as follows:

Place value	2^4	2^3	2^2	2^1	2^0
	16	8	4	2	1
Number	1	0	1	1	0

The number $10110_{(2)}$, then, is 1(16) + 0(8) + 1(4) + 1(2) + 0(1) = $22_{(10)}$

Notice that place value in base two has a different value than the same place in base ten.

COUNTING IN BASE TWO AND BASE TEN

In base ten, when counting from 0, the numbers are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. The next number to be counted is ten, but there is no single symbol in base ten to indicate the next number. Therefore, a combination of symbols is used by repeating the 0 and indicating a 1 in the tens column. This means one group of tens and no groups of units.

When counting in base two, there are only two digits or symbols, 1 and 0. The same mechanical process is used in base two that was used in base ten. Starting with 0, in base two, the count is 0, 1.

There are no other symbols to indicate the next number so a 1 is written in the next place value column to the left and a 0 is written in the first place value column; that is, 0, 1, $10_{(2)}$.

This last number, then, indicates one group of two and no groups of units. The next number is $11_{(2)}$, which means one group of twos and one group of units. A number such as $1101_{(2)}$ would indicate one group of eights, one group of fours, no group of twos, and one group of units, and in this case is the same as decimal number 13.

Counting comparisons between the decimal and binary systems are made as follows:

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001

Notice that when counting objects, the decimal 17 and binary 10001 refer to the same object; therefore, decimal 17 must be equivalent to binary 10001.

CONVERSIONS

If the binary number 101 is to be converted to a decimal number, the binary number is written in expanded notation; that is

$$101_{(2)} = 1(4) + 0(2) + 1(1)$$

and the indicated multiplication, by terms, is carried out and yields

$$4 + 0 + 1 = 5$$

The 5 is a base ten number; that is, if objects were counted in a row and stopped with the decimal 5 and then the same objects were counted again in binary, the same object would be indicated with one-zero-one ($101_{(2)}$).

Example: Convert $11101_{(2)}$ to base ten.

Solution: Write $11101_{(2)}$ in expanded notation as

$$1(16) + 1(8) + 1(4) + 0(2) + 1(1)$$

and carry out the multiplication to obtain

$$16 + 8 + 4 + 0 + 1 = 29$$

To convert the decimal number 26 to binary, first intuitively determine the largest place value column contained in the number; that is, in the place value chart

2^5	2^4	2^3	2^2	2^1	2^0
32	16	8	4	2	1

there is one group of 16 or 2^4 in 26. Also, there must be five digits in the representation of 26 in binary because the place value column for 2^4 is the fifth place value column from the right. This is indicated by drawing lines for each digit as follows:

2^4	2^3	2^2	2^1	2^0
-	-	-	-	-

There is one group of 16 in 26; therefore, write

2^4	2^3	2^2	2^1	2^0
1	-	-	-	-

Sixteen is indicated, leaving 26 - 16 to be accounted for, or ten. There is one group of 2^3 in ten so write

2^4	2^3	2^2	2^1	2^0
1	1	-	-	-

After accounting for one group of 16 and one group of 8, 2 is left. There are no groups of 2^2 in 2 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	-	-

and then find there is one group of 2^1 in 2 and write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	-

leaving 0. Finally there is no group of 2^0 in 0 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	0

herefore, 26 in decimal is equal to 11010 in inary.

This type conversion becomes complicated in ealing with large numbers. There is a techique which enables us to convert from decimal o binary quite simply by continual division of he decimal number by the base of the binary ystem, indicating the remainder after each ivision operation until the quotient is zero. his is shown in the following:

Convert 26 decimal to binary—

2|26
13 remainder is 0

2|13
6 remainder is 1

2|6
3 remainder is 0

2|3
1 remainder is 1

2|1
0 remainder is 1

The remainders are read from the bottom to the top to obtain the binary equivalent of the decimal number; that is,

$$26 = 11010_{(2)}$$

The division process may be combined as follows:

Convert 38 to binary—

2|38
2|19 0
2|9 1
2|4 1
2|2 0
2|1 0
0 1

and the binary equivalent of 38 is $100110_{(2)}$.

BINARY ARITHMETIC

Familiarity with the basic arithmetic operations in the binary system is needed in order to enhance the understanding of computers; therefore, a comparison between the decimal and binary systems will be made.

Addition

When counting in the decimal system, a limit is reached where the next number cannot be indicated in a single column; that is, when counting from 0 to 9.

At this point a "carry" is made; that is, the first digit (0) is repeated, and a 1 is indicated in the tens column. This means one group of tens and no groups of units, and is indicated by 10.

The ADDITION facts of the DECIMAL system are shown in the truth table below:

+	0	1	2	3	...
0	0	1	2	3	...
1	1	2	3	4	...
2	2	3	4	5	...
3	⋮	⋮	⋮	⋮	

For example:

+	0	1	2	3
0				↓
1				↓
2	→	→	→	5
3				

means

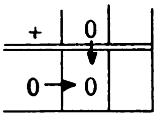
$$2 + 3 = 5$$

Binary addition is similar to decimal addition, except in binary only two digits, 0 and 1, are available. The mechanical procedure is the same.

The ADDITION facts of the BINARY system are as follows:

+	0	1
0	0	1
1	1	10

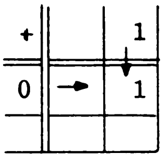
That is,



means

0 + 0 = 0

and



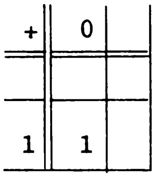
means

0 + 1 = 1

or

1 + 0 = 1

and



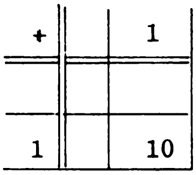
means

1 + 0 = 1

or

0 + 1 = 1

and



means

1 + 1 = 10

This means that

0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 10

When adding numbers in base ten, the following mechanical procedure is followed:

Add 172 and 32

```
  172
+  32
 ----
  104   partial sum
+ 100   carry overs
 ----
  204   final sum
```

When adding two binary numbers, the process is

```
 0101
+0111
 ----
 0010   partial sum
+1010   carry overs
 ----
 1000   partial sum
+0100   carry overs
 ----
 1100   final sum
```

The previous addition may be stated as follows:

Starting from the right column, one plus one equals 0 and 1 carry. The carry plus zero plus one equals zero and one carry. The carry plus one plus one equals one and one carry. The carry plus zero plus zero equals one.

Computer Addition

The computer technique of addition utilizes the process of half add, carry, and final sum. Half add means to add two digits and neglect the carry. The carry is written shifted left (which is explained later in the arithmetic circuits of this chapter) below the half add sum and then added o this half add sum. An example in decimal is as ollows:

dd 3562 and 2149

$$\begin{array}{rl} 3562 & \\ +\ 2149 & \\ \hline 5601 & \text{half add} \\ +\ 0110 & \text{carry overs} \\ \hline 5711 & \text{final sum} \end{array}$$

f other CARRYOVERS are required, they are andled as follows:

dd 4965 and 5247

$$\begin{array}{rl} 4965 & \\ +\ 5247 & \\ \hline 9102 & \text{half add} \\ +\ 1110 & \text{carry overs} \\ \hline 0212 & \\ +\ 10000 & \text{carry overs} \\ \hline 10212 & \text{final sum} \end{array}$$

The computer technique is used in binary as it is used in decimal.

Example: Add the binary numbers 11101 and 1101.

Solution:

$$\begin{array}{rl} 11101 & \\ +\ 1101 & \\ \hline 10000 & \text{half add} \\ +\ 11010 & \text{carry overs} \\ \hline 01010 & \text{half add} \\ +\ 100000 & \text{carry overs} \\ \hline 101010 & \text{final sum} \end{array}$$

Example: Add the binary numbers 1101 and 110.

Solution:

$$\begin{array}{rl} 1101 & \\ +\ 110 & \\ \hline 1011 & \text{half add} \\ +\ 1000 & \text{carry over} \\ \hline 0011 & \text{half add} \\ +\ 10000 & \text{carry over} \\ \hline 10011 & \text{final sum} \end{array}$$

Subtraction

Both the direct and complement methods of subtraction are discussed. The methods are compared in the decimal and binary systems.

DIRECT SUBTRACTION.—In the decimal system, when subtractions are made, the terms to be subtracted are named as follows:

$$\begin{array}{rl} 7 & \text{minuend} \\ -\ 2 & \text{subtrahend} \\ \hline 5 & \text{difference} \end{array}$$

In cases where the subtrahend, in a particular column, is greater than the minuend, a borrow must be made; that is, a digit must be moved from a higher place value column to a lower place value column. An example is

$$\begin{array}{r} 76 \\ -\ 39 \\ \hline \end{array}$$

where 9 is to be subtracted from 6.

In this case one group of tens must be borrowed from the 7 group of tens. This is shown by

$$\begin{array}{r} 76 \\ -\ 39 \\ \hline \end{array}$$

is

$$\begin{array}{rr} & 10 \\ 6 & 6 \\ -\ 3 & 9 \\ \hline \end{array}$$

and 9 from 16 is 7. Therefore,

$$\begin{array}{rr} 6 & 16 \\ -\ 3 & 9 \\ \hline 3 & 7 \end{array}$$

This concept may be applied to as many columns as necessary. For example, in the problem

$$\begin{array}{r} 9326 \\ -\ 7438 \\ \hline \end{array}$$

one group of tens is borrowed from the two groups to give

$$\begin{array}{rr} & 10 \\ 931 & 6 \\ -\ 743 & 8 \\ \hline & 8 \end{array}$$

then one group of hundreds is borrowed from the three groups to give

$$\begin{array}{rrr} & 10 & 10 \\ 92 & 1 & 6 \\ -\ 74 & 3 & 8 \\ \hline & 8 & 8 \end{array}$$

The next step is

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -\ 7 & 4 & 3 & 8 \\ \hline & 8 & 8 & 8 \end{array}$$

and finally

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -7 & 4 & 3 & 8 \\ \hline 1 & 8 & 8 & 8 \end{array}$$

The subtraction problem difference may be verified by adding the difference to the subtrahend to give the minuend. This shown by

$$\begin{array}{r} 1888 \\ +\ 7438 \\ \hline 9326 \end{array}$$

Binary subtraction problems are solved in the same manner as decimal subtraction problems except base two is used. One fact may cause problems; that is, when 1 is subtracted from 0, the difference is 1 if a borrow of 1 is made. An example of this is the following:

$$\begin{array}{r} 10 \\ -\ 1 \\ \hline \end{array}$$

A borrow of 1 is made, to give

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline \end{array}$$

10 (which must be read as "one-zero," and n as "ten") in base two, really 2 in decim and 1 from 2 is 1. Therefore,

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline & 1 \end{array}$$

When no 1 is available in the next highe place value column, a higher place value column must be used. This is shown in the following example of binary subtraction:

$$\begin{array}{r} 100 \\ -\ 1 \\ \hline \end{array}$$

A borrow from the 2^2 column is made, giving 10 in the 2^1 column.

$$\begin{array}{rrr} & 10 & \\ 0 & 0 & 0 \\ - & & 1 \\ \hline \end{array}$$

Then, a borrow of 1 is made from the 10 in the 2^1 column, leaving 1 in this column and giving a 10 in the 2^0 column, and 10 minus 1 is 1,

$$\begin{array}{rrr} & & 10 \\ 0 & 1 & 0 \\ - & & 1 \\ \hline \end{array}$$

Therefore,

$$\begin{array}{rrrl} & & 10 & \\ 0 & 1 & 0 & \text{minuend} \\ - & & 1 & \text{subtrahend} \\ \hline 0 & 1 & 1 & \text{difference} \end{array}$$

Verification of this difference is made by adding the subtrahend to the difference to yield the minuend.

$$\begin{array}{r} 011 \\ +\ 1 \\ \hline 100 \end{array}$$

SUBTRACTION BY COMPLEMENTS (BASE TEN).—Digital computers are generally unable to perform subtraction in the manner previously discussed because the process of borrowing involves operations which are impractical to incorporate into a machine. The process which olves complements is used in digital com-ers. Complement means the number or quan-y required to fill or complete something. e complement of a number is therefore, other number which completes the original mber with respect to a known reference.

For example, the nine's complement of a mber is that number that when added to the iginal number will yield all nines in the ace value columns used. An example of this as follows.

What is the nine's complement of 32?
What number, when added to 32, will produce 99?

tuitively, it can be seen that the number is

$$99 - 32$$

r

$$67$$

one is now added to the nine's complement, e ten's complement results; that is,

$$67 + 1 = 68$$

nd 68 is the ten's complement of 32. Notice hat if 68 is added to 32, the sum is 100. Thereore, the ten's complement of a number is efined as that number which, when added to the riginal number, yields a 1 in the next higher lace value column and zeros in all other colmns. The ten's complement of 78 is

$$100 - 78 = 22$$

otice that the ten's complement is in reference o a power of ten one place value higher than he highest place value of the original number.

Number	Ten's complement	Reference
7	3	10^1
21	79	10^2
309	691	10^3

Rather than subtract the subtrahend from the minuend, the ten's complement of the subtrahend (found with reference to the power of ten one place value higher than either the subtrahend or minuend) may be added to the minuend and then decrease this sum by the reference power of ten used to obtain the difference. A step-by-step process is shown to explain the preceding statement.

Example: Subtract 26 from 49

Solution: Write

$$\begin{array}{r} 49 \\ -\ 26 \\ \hline \end{array}$$

then find the ten's complement of 26 which is

$$100 - 26 = 74$$

This may be rearranged as follows:

$$100 - 74 = 26$$

Now, instead of writing

$$49 - 26$$

write

$$\begin{aligned} & 49 - (100 - 74) \\ = {} & 49 - 100 + 74 \\ = {} & 49 + 74 - 100 \\ = {} & 23 \end{aligned}$$

This indicates that the minuend (49) plus the ten's complement of 26 (74) are added, then the reference power of ten used (100) is subtracted to give the difference which is 23. Notice that

$$\begin{aligned} & 49 - 26 \\ = {} & 49 + 74 - 100 \\ = {} & 123 - 100 \\ = {} & 23 \end{aligned}$$

the digit (1) found in the place value column higher than the highest place value column of the subtrahend had only to be dropped. Always, this digit (1) which is developed indicates the difference (23) is a positive value.

Example: Subtract 36 from 429

Solution: Write

$$\begin{array}{rl} 429 & \text{minuend} \\ -\ 36 & \text{subtrahend} \\ \hline \end{array}$$

then

```
        429   minuend
      + 964   tens complement of
      -----   subtrahend
       1|393
    ---|
     = +|393  remainder
    ---'
```

The process of subtracting a larger number from a smaller number, using the ten's complement, is slightly different from the example previously shown. Instead of a 1 in the higher place value column, a zero will be present. The complement of the apparent remainder will indicate the actual negative remainder.

Example: Subtract 362 from 127

Solution: Write

```
        127   minuend
      - 362   subtrahend
      -----
```

then

```
        127   minuend
      + 638   ten's complement of
      -----   subtrahend
          |
         0|765   apparent remainder
      ---|
      = -|235   ten's complement of
      ---'      apparent remainder
```

which is

- 235 actual negative remainder

SUBTRACTION BY COMPLEMENTS (BASE TWO).—Digital computers use the complementary addition technique for subtraction, which has been discussed in decimal notation; and they also use the base two system. The process for base two is similar to that for base ten.

The one's complement of a binary number is that number with all 1 digits changed to 0's and all 0 digits changed to 1's. This process is termed inversion. Therefore, the ones complement of 10110 is 01001. The two's complement of a binary number is its one's complement plus 1; that is,

Number	One's complement	Two's compleme
01	10	11
111	000	001
1110	0001	0010

Notice that the number 01 plus its two's com plement 11 equals 100 which is a 1 in the ne higher place value column followed by zero

The two's complement may also be dete mined by inverting every digit after the fir one (1); that is, starting with the smallest pla value and moving toward the largest place valu (right to left). This method is normally le time consuming than determining the one's com plement and then adding one to form the two complement. For example: the two's comple ment of

```
       001101011 | 10      The first one (fro
                 |
       invert all|          right to left) do
is     ----------|
       110010100 | 10      not invert.
                 |
```

This indicates that the same procedure use for decimal numbers may be used for binar numbers to perform subtraction by the additio of the complement.

Example: Subtract the binary number 0110 from the binary number 11001.

Solution: Write

```
        11001   minuend
      - 01101   subtrahend
      -------
```

then

```
        11001   minuend
      + 10011   two's complement of th
     |-------   subtrahend
     |
     |1 01100   difference
   --|
    =|+ 01100   positive difference
   --'
```

Notice that the same number of place value col umns must be used in both the subtrahend an minuend.

Example: In binary, subtract 1110 from 1111.

olution: Write

1111 minuend
- 1110 subtrahend

en

1111 minuend
+ 0010 two's complement of the subtrahend

1|0001 difference

= +|0001 positive difference

s in the decimal system, if a one is developed, t indicates plus. If a zero is present, it indiates a negative apparent answer and the comlement of the apparent answer is used, receded by a minus sign.

Example: In binary, subtract 1011 from 1001.

Solution: Write

1001 minuend
- 1011 subtrahend

hen

1001 minuend
+ 0101 two's complement of the subtrahend

0|1110 apparent difference

-|0010 two's complement of the apparent difference

-|0010 negative difference

Multiplication

The direct method of multiplication of decimal numbers is shown in the following example.

Example: Multiply 32 x 25

Solution: Write

25 = 20 + 5

then

32 (20 + 5)

Using the distributive principle

32 (20 + 5)
= 32 (20) + 32 (5)
= 640 + 160
= 800

The same problem written as

32
x 25

gives

32 x 5
= 160 partial product

and

32 x 20
= 640 partial product

then

160 + 640
= 800 product

The technique generally used is

32
x 25
160
64
800

Notice that the 64 really represents 640, but the zero is omitted.

Direct binary multiplication uses the same technique as direct decimal multiplication.

Example: Multiply the following binary numbers.

110 and 1101

Solution: Write

1101
x 110
0000
1101
1101
1001110

This may be verified by changing the factors to decimal, multiplying and obtaining the decimal product, then changing the decimal product back to binary.

Repetitive Addition

The idea that multiplication is repetitive addition is of beneficial use when working with computers. When multiplication is to be accomplished with a computer, the process of repeated addition is used.

If two numbers are to be multiplied together, write the following:

Multiply

$$231 \text{ by } 45$$

Write

$$231\ (40 + 5)$$

then

$$(231 \times 40) + (231 \times 5)$$

Multiplying each term gives the following:

$$\begin{array}{r}231\\ \times\ \ 40\\ \hline 9240\end{array} \quad \text{and} \quad \begin{array}{r}231\\ \times\ \ 5\\ \hline 1155\end{array}$$

Notice that 231 could have been added forty times to satisfy one half of the above problem and 231 could have been added five times to satisfy the other half.

$$\begin{array}{r}\left.\begin{array}{r}231\\ 231\\ 231\\ 231\\ ''\\ ''\\ ''\\ +\ 231\end{array}\right\}\text{40 times}\\ \hline 9240\end{array} \qquad \begin{array}{r}\left.\begin{array}{r}231\\ 231\\ 231\\ 231\\ 231\\ +\ \ 231\end{array}\right\}\text{5 times}\\ \hline 1155\end{array}$$

Rather than write 231 forty times, 2310 co have been written four times; that is,

$$\begin{aligned} & 231 \times 40\\ = {} & 231 \times 4 \times 10\\ = {} & 231 \times 10 \times 4\\ = {} & 2310 \times 4 \end{aligned}$$

$$\begin{array}{r} = 2310\\ 2310\\ 2310\\ +\ 2310\\ \hline 9240\end{array}$$

$$9240 + 1155 = 10395$$

When the repetitive addition type of mult plication is used in a computer, it appea as follows. Two registers are used; the a cumulator and the multiplier. The accumulat maintains a constant subtotal, and the multipli keeps account of the addition to be perform

The problem is to multiply 231 by 45.

Accumulator	Multiplier	
000000 + 000231	45	These operations represent the five ones
000231 + 000231	44	
000462 + 000231	43	
000693 + 000231	42	
000924 + 000231	41	
001155 + 002310	40	These operations represent the four tens
003465 + 002310	30	
005775 + 002310	20	
008085 + 002310	10	
0010395	00	

Notice that the multiplier indicates the num- r of times the number 231 is added and the cumulator maintains the subtotal. When the ultiplier indicates 40, the 231 is changed to 310 and the multiplier then would indicate ad- tion of the 2310 four times. The overall effect to move the zero in the 40 to the 231.

The binary system follows the previous tech- iques as shown in the following example.

Multiply 1011 by 1101.

Accumulator	Multiplier
00000000	1101
+ 00001011	
00001011	1100
+ 00101100	
00110111	1000
+ 01011000	
10001111	0000

ivision

The direct method of division of decimal umbers is shown in the following example:

Example: Divide 30 (dividend) by 5 (divisor).

Solution: Write

$$5\overline{)30}$$

Five is not contained in 3 but is contained in 0. How many 5's are contained in 30? The nswer is 6, so write 6 above the zero

$$\begin{array}{r} 6 \text{ (quotient)} \\ 5\overline{)30} \end{array}$$

Multiply the 6 and 5 together and find the prod- ct which is 30. Write 30 under the 30 and subtract.

$$\begin{array}{r} 6 \\ 5\overline{)30} \\ \underline{30} \\ 0 \end{array}$$

There are no 5's in zero; therefore, the answer is 6.

Direct binary division follows the same procedure.

Example: Divide 1110 by 111.

Solution: Write

$$111\overline{)1110}$$

There is one 111 in 111 so write 1 above the right hand one in 111 as follows:

$$\begin{array}{r} 1 \\ 111\overline{)1110} \end{array}$$

Multiply 111 by 1 and write the product under the 111, and subtract, and bring down the last zero.

$$\begin{array}{r} 1 \\ 111\overline{)1110} \\ \underline{111} \\ 0000 \end{array}$$

There are no 111's in 0000; therefore, write zero after the 1 in the answer and find 10 is the answer.

$$\begin{array}{r} 10 \\ 111\overline{)1110} \\ \underline{111} \\ 0 \\ 0 \end{array}$$

Example: Divide 10010 by 110, all in binary.

Solution: Write

$$\begin{array}{r} 1 \\ 110\overline{)10010} \end{array}$$

Multiply quotient and divisor and subtract from dividend

$$\begin{array}{r} 1 \\ 110\overline{)10010} \\ \underline{110} \\ 11 \end{array}$$

Bring down last zero.

$$\begin{array}{r} 1 \\ 110\overline{)10010} \\ 110 \\ \hline 110 \end{array}$$

Find 110 goes into 110 one time and write

$$\begin{array}{r} 11 \\ 110\overline{)10010} \\ 110 \\ \hline 110 \end{array}$$

Multiply quotient and last dividend digit and find

$$\begin{array}{r} 11 \\ 110\overline{)10010} \\ 110 \\ \hline 110 \\ 110 \\ \hline 000 \end{array}$$

and the answer is 11.

Repetitive Subtraction

In multiplication repeated addition is used; in division, repeated subtraction is used.

If one number (the dividend) is to be divided by another number (the divisor), write the following:

Divide 126 by 6

Write

$$\begin{array}{r} 126 \\ -\ 6 \\ \hline 120 \\ -\ 6 \\ \hline 114 \\ -\ 6 \\ \hline 108 \\ -\ 6 \\ \hline '' \\ '' \end{array}$$

Subtracting 6 from 126 twenty-one times regi ters a zero remainder. A computer does same thing except it utilizes power of te Use is still made of the accumulator and registe as in repetitive addition but the technique i reversed.

Example: Divide 40320 by 126.

Accumulator	Quotient register	
40320		(a) Put the dividendi the accumulator
	0000	(b) Set the register t zero.
- 12600		(c) Put the divisor i the largest powe of ten that is equa to or less than th value of the dividend that is in th accumulator.
	+ 0100	(d) Put the power o ten into the register.
27720		(e) Subtract.
	+ 0100	(f) Add the sums i the quotient regis ter.
- 12600	+ 0100	(g) Repeat steps (c (d), (e), and (f) a shown.
15120	0200	
- 12600	+ 0100	
2520	0300	
- 1260	+ 0010	
1260	0310	
- 1260	+ 0010	
0000	0320 Answer	

Example: Divide 126 by 6.

Accumulator	Quotient register
126	000
-60	+ 010
066	010
- 60	+ 010
006	020
- 6	+ 001
000	021 Answer

The same procedure applies to binary divi-
except the highest power of 2 (in binary) is
l.

Example: Divide 100111 by 11.

ccumulator	Quotient register	
100111	00000	
- 11000	+ 01000	Add 2^3 to quotient register.
1111	01000	
- 1100	+ 00100	Add 2^2 to quotient register.
11	01100	
- 11	+ 00001	Add 2^0 to quotient register.
0	01101	Answer.

CODING

As stated previously, electronic circuit ele-
nts of computers are inherently binary; that
they will have two stable states. Therefore,
base ten numbering system cannot be used
iciently in computers. While people commu-
ate and calculate using letters of the alphabet
l numbers of the decimal system, digital
nputers communicate and calculate using
ups of binary symbols called codes.

Coding is the means by which data in one
rm is represented in another form which is
ceptable to the computer. A form of coding
used in the Morse code in which letters are
presented by dots and dashes. This makes
alphabet acceptable to transmission by radio.

Of the many coding systems, three of the
ost common ones are discussed. Memorization
these codes is not necessary, but understand-
g of the reasons for the codes is desirable.

NARY CODED
ECIMAL (B.C.D.)

This code makes use of groups of binary bits
inary symbols) to represent a decimal digit.
the decimal system there are only ten digits;
erefore, only ten groups of binary bits must
remembered, EACH DECIMAL DIGIT IS
EPRESENTED BY A GROUP OF FOUR BI-
ARY BITS. The ten groups to remember are
follows:

Decimal digit	Binary - coded decimal digit
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1

To write ten in B.C.D., the use of two groups is required; that is,

Decimal	1 /	0 \
B.C.D.	0001	0000

Any two-digit decimal number requires two groups of B.C.D.,etc.

Decimal	7 /	3 /	8 \
B.C.D.	0111	0011	1000

The separation of the B.C.D. groups is shown for ease of reading and does not necessarily need to be written as shown; 738 could be written as 011100111000. One advantage of the B.C.D. over true binary is ease of determining the decimal value. This is shown as follows:

B.C.D.	0111	0011	1000
= decimal	7	3	8

738 in true binary is 1011100010
and, true binary 1011100010

$$= \text{decimal } 1(2^9) + 0(2^8) + 1(2^7) + 1(2^6)$$

$$+ 1(2^5) + 0(2^4) + 0(2^3) + 0(2^2)$$

$$+ 1(2^1) + 0(2^0)$$

$$= 512 + 128 + 64 + 32 + 2 = 738$$

The ease of converting from decimal to B.C.D. and from B.C.D. back to decimal should be apparent.

One serious disadvantage of the B.C.D. is that this code cannot provide a decimal carry. The following examples show this.

Example: Add the following:

Decimal		B.C.D.
5	=	0101
+ 3	=	0011
8	=	1000

Notice that there is no carry in the decimal addition and the answer in B.C.D. is equal to the answer in decimal. The B.C.D. is in corrrect notation and does exist.

Example: Add the following:

Decimal		B.C.D.
8	=	1000
+ 5	=	0101
13	=	1101

Notice that the B.C.D. answer is correct in true binary, but $1101_{(2)}$ does not exist in B.C.D. the correct B.C.D. answer for 13 should be 0001 0011. Therefore, when a carry is made in decimal, the B.C.D. cannot indicate the correct answer in B.C.D. form.

Excess Three Code

The excess three code is used to eliminate the inability of the binary carry. It is really a modification of the B.C.D. so that a carry can be made.

To change a B.C.D. number to excess three, add three to the B.C.D.

B.C.D.	1000
	+ 0011
Excess three	1011

In excess three code 1011 is 8 in decimal. The following chart shows the decimal, B.C.D., and the excess three code.

Decimal	B.C.D.	Excess three
0	0000	0011
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

As previously stated, the excess three cod will provide the capability to carry in binary The following is for explanation.

Example: Add $6_{(10)}$ and $3_{(10)}$ in excess thre

Solution: Write

Decimal		Excess three with three groups possible		
6	=	0011	0011	1001
+ 3	=	0011	0011	0110
9				

Notice that in group one the six and thre are indicated. In groups two and three a zer (0011) in excess three is indicated.

Add as follows

0011	0011	1001	(Excess three)
0011	0011	0110	(Excess three)
0110	0110	1111	(Excess six)

But our answer is in excess six. Therefore, three must be subtracted from each group i order to return our answer to excess three.

0110	0110	1111	
- 0011	- 0011	- 0011	
0011	0011	1100	(Excess three)
0	0	9	Answer in decimal

When a carry is developed in any group, the following procedure is used.

Example: Add $9_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal	Excess three				
9	0011	0011	1	1100	(Excess 3)
+ 3	0011	0011		0110	(Excess 3)
12	0110	0111		0010	(Excess 6)

NOTE: Since group one created a carry, as shown, three must be added instead of subtracted in order to place group one into excess three. The other groups follow the previous example.

0110	0111	0010	(Excess six)
- 0011	- 0011	+ 0011	
0011	0100	0101	(Excess three)
0	1	2	

The above procedure will hold for any number of group indicators the computer possesses.

A further advantage of excess three code is the ease with which the nine's complement of a number indicated in excess three may be found; that is, the nine's complement of 7, indicated in excess three as 1010, is found by inverting each digit in 1010 to read 0101. This 0101, in excess three, is 2, which is the nine's complement of 7.

The following table shows the nine's complement of the decimal digits.

Decimal	Excess three	Excess three inverted	Nine's complement
0	0011	1100	9
1	0100	1011	8
2	0101	1010	7
3	0110	1001	6
4	0111	1000	5
5	1000	0111	4
6	1001	0110	3
7	1010	0101	2
8	1011	0100	1
9	1100	0011	0

GRAY CODE

This code is a modification of the binary counting system. In the Gray code sequence counting, only one bit will change as each count proceeds. When counting in binary from $7_{(10)}$ ($0111_{(2)}$) to $8_{(10)}$($1000_{(2)}$), notice that four bits have to be changed.

The Gray code is shown for comparison

Decimal number	Pure binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

In the Gray code when counting from $7_{(10)}$(0100) to $8_{(10)}$(1100), notice that only one bit changes.

One of the primary purposes of this code is the reduction of operational errors by changing only one digit at the time during the process of converting mechanical changes into numerical expressions. For example, to convert the shaft rotation (output of an analog computer) from seven to eight degrees would require only a change of one bit as previously indicated.

To convert a binary code to its Gray code equivalent, the following addition WITHOUT CARRY is used.

Example: Convert binary 0100 to its Gray code equivalent.

Solution: Keep the most significant bit as is.

Binary	0	1	0	0
Gray	0	_	_	_

Next, add horizontally the most significant bit to the next significant bit in the binary number and carry the sum to the Gray code as follows:

Binary	0	1	0	0
Gray	0	1	_	_

now add and continue as shown

Binary 0 1 0 0
Gray 0 1 ① _

then

Binary 0 1 0 0
Gray 0 1 1 ⓪

Therefore, 0100 binary is equivalent to 0110 in the Gray code.

Example: Convert $14_{(10)}$ to Gray code.

Solution: Write

Decimal 14 = 1110 binary

Binary ① 1 1 0
Gray ① _ _ _

then

Binary 1 1 add without
Gray 1 ⓪ _ _ the carry

then

Binary 1 1 1 0
Gray 1 0 ⓪ _

then

Binary 1 1 1 0
Gray 1 0 0 ①

therefore, 1110 binary is equivalent to 1001 in Gray code.

A method is also needed to convert Gray code to binary code.

Example: Convert 1001 in Gray code to binary.

Solution:

Gray ① 0 0 1 Retain the most significant
Binary ① _ _ _ Gray code bit.
Gray 1 ⓪ 0 1 Add diagonally without a
Binary ① 1 _ _ carry.
Gray 1 0 ⓪ 1 Continue diagonal addition
Binary 1 ① 1 _
Gray 1 0 0 ① Continue.
Binary 1 1 ① 0 Therefore, Gray 1001 is equivalent to binary 1110.

OCTAL NUMBERS

Octal numbers are base eight numbers; that is, there are only eight digits in base eight. These are 0, 1, 2, 3, 4, 5, 6, and 7. Because eight is a power of two, the octal system has special characteristics that make it especially useful in situations involving binary numbers. This is illustrated as follows:

A decimal number can be converted to octal by the same method described for decimal to binary. To change 334 to octal write

	Remainder
8/334	
8/41	6 ↑
8/5	1
0	5

Therefore,

$$334 \text{ decimal} = 516 \text{ octal or } 516_{(8)}$$

The same decimal number when changed to binary is 101001110.

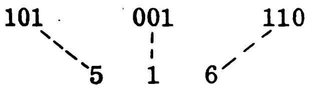
Since things equal to the same thing are equal to each other

$$516_{(8)} = 101001110_{(2)}$$

Notice that the true binary number is sepa-ted into groups of three digits from the right follows:

101 001 110

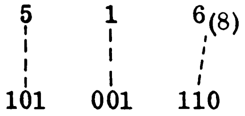
d by observation, notice that each group rep-sents the following:



ich is 516 in octal.

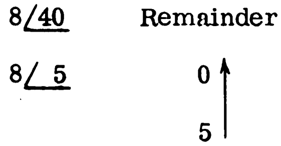
To convert from binary to octal, it is only cessary to divide the binary number into oups of three and read each group as the oc- representation in place value.

To convert from octal to binary, the reverse eration is used; that is,



Example: Convert 40 decimal to octal, then binary.

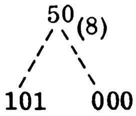
Solution: Write



erefore,

$$40_{(10)} = 50_{(8)}$$

l then

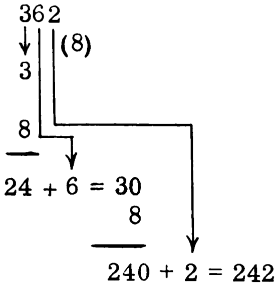


The preceding conversions from binary to al and from octal to binary are possible be-se 2^3 is the same as 8^1.

The octal number system affords many con-iences. When recording a binary number paper, it is usually more convenient to write n octal. For example, computer programmers l programming manuals use the octal system as a convenient notation for binary numbers. Also, when converting a large decimal number to binary, it is usually more convenient to convert it to octal first and then to binary since fewer divisions are required in dividing a decimal number by 8 instead of 2.

A number in any base that is smaller than ten can be converted to a number in base ten (decimal) by the following method: Multiply the most significant digit (MSD) by the present (old) base, add the next MSD to the product of the last multiplication and multiply the sum by the present (old) base, continuing until the least significant digit (LSD) is added.

Example: Convert to decimal



BASIC PRINCIPLES

In contrast to analog devices, digital computers use discrete values to represent the digits 1 and 0, and the computations are performed by simple electronic switches and circuits. A fundamental difference between the two types is that the analog computer is continuously presenting a solution to the problem, while the digital computer performs each computation separately. In other words, when one of the factors in a problem changes, the solution presented by the analog computer changes continuously as the inputs change. In a digital computer, the entire computation must be done again after each increment of change in the input.

Most of the computers used in fire control are part of control systems where time is a factor in the problem. The computer receives information from radar and other sources, and makes decisions, which are presented at the output to control some specific operation, such as target/missile intercept point.

An automatic digital computer generally consists of five major units: input, control, memory, arithmetic, and output. A simple block diagram appears in figure 7-1.

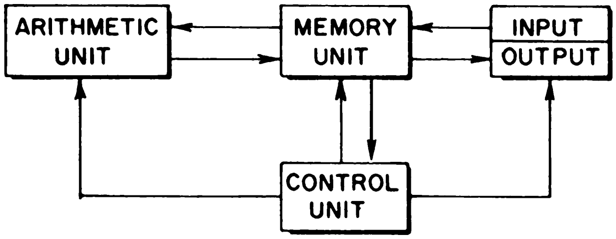


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Figure 7-1.—Fundamental units of a digital computer.

INPUT UNIT

For a computer to perform a specified series of operations, it must be fed both the instructions and the data to be used in the computations. Many different devices are used to properly present the information to the computer. Examples are modified electric typewriters, punched card and punched tape readers, magnetic tape readers, and manual input devices such as pushbuttons or toggle switches. In fire control applications the most common input device is the analog to digital converter which changes the proportional voltage and current analogs into the digital form required by the numbering system used in digital computers.

CONTROL AND ARITHMETIC UNITS

The control unit of a computer ties all parts of the computer together, causing them to function as an integrated system. Its functions are the same as for the control unit of any system: it commands complete control over every operation the computer performs.

The arithmetic unit is the calculating unit. It contains circuits that are simple in both theory and operation. It performs mathematical operations—addition, subtraction, multiplication, and division—by performing logical operations. It must be remembered that all mathematical calculations dealing with numbers take some form of one or more of these basic operations. For instance, squaring a number is merely a special form of multiplication; extracting a square root involves all four operations in a special order. Similarly, an exponential curve is simply the result of many instantaneous values computed by arithmetic means.

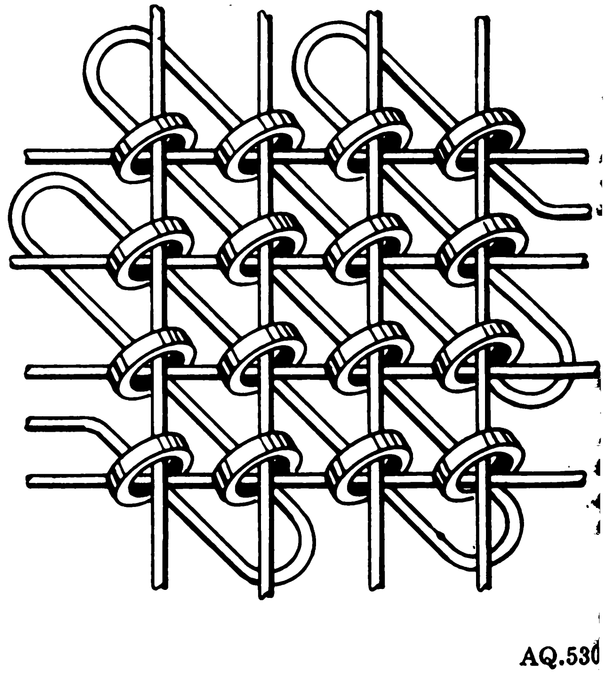
By comparing data quantities against each other, the arithmetic unit is able to make logical decisions. For example, it can determine the proper weapon line by considering tar speed, wind velocity and direction, drift, ba listics information regarding the particular we pon, and other factors that have been fed it, and then provide a "yes or no" answer specific questions. The solution to a given proble is sent from the arithmetic unit to the memo unit where it remains in storage until need for further calculations, or until otherwise rout by the control unit.

Although logic decisions are usually made the arithmetic unit, they are also made the other major units of the computer.

MEMORY UNIT

The memory or storage section of the com puter is used to store the information which used during the computational process. It stor both the program instructions and the da used in the computation. The memory can b used to hold both intermediate and final results as the computer goes through the program Common memory devices include: magnetic cores, magnetic drums, magnetic tapes, ultrasonic delay lines, and flip-flops.

Figure 7-2 shows a magnetic core memory Each core can be magnetically saturated t



AQ.530
Figure 7-2.—Magnetic core memory cell.

ither the 1 or the 0 polarity. Therefore, each ore can hold just one bit of data at a given time.

Regardless of the type of memory employed, t is divided into a number of locations, each of hich is identified by an address. When the ontrol unit calls for an instruction from the rogram or a piece of information which is tored in the memory, it acquires the informaon by using the proper address to establish e path to the appropriate memory element and he data stored there. The normal construcion of storage devices makes any address ccessible. However, the length of time required o obtain the information is determined by the ype of storage device. This type of accessiility is referred to as random or sequential ccess.

The information stored at each address is eferred to as a "word." Each word is repreented by a number of pulses or signal voltage evels. The storage can be accomplished on ape, magnetic devices, or special circuits. A ord can represent either a numerical quantity r a computer instruction, but only one word an be stored in any given address.

The velocity of light is the upper speed imit at which a digital computer can pass data rom one unit to another.

In serial form, the individual instructions and nformation bits are fed step after step, one bit t a time. This is a comparatively slow process, ut may be accomplished with few and simple ircuits. Parallel input permits a number of its to be fed at the same time, resulting in a uch faster rate. More complex circuitry is required for parallel inputs. In a practical computer, instructions and information may be fed nto the computer at the rate of 3 million bits er second, using the parallel input. Rates as igh as 50,000 bits per second are common, sing serial feed systems.

UTPUT UNIT

After the computer has done the computaions, there must be some method of communicating the results to the operator. The devices sed to "read out" the results are similar to hose used in the input: punched cards or tape, agnetic tape, and so forth. Specialized output evices include audio or video displays and digital to analog converters.

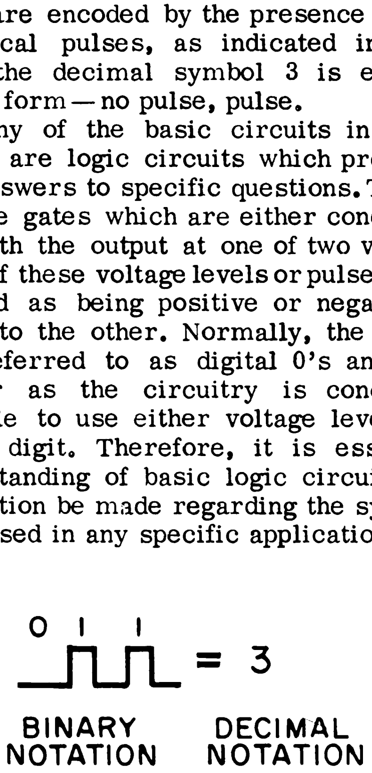
Several special facilities are included in igital computers. When an operation is to be erformed in an arithmetic unit, only one word t a time can be transferred from the memory unit. To perform an operation with two words, the first word must be stored momentarily while the second word is being transferred. For this function, the arithmetic unit has a special memory cell called an accumulator.

The accumulator is one of a class of memory devices called registers. A register is simply a means of storing temporarily a certain amount of information. The methods of storage may be the same as those used in the memory, but the register can only store one word at a time. Other registers are used in the computer, such as the instruction register associated with the control unit which allows reference to the instruction being interpreted during the time control signals are being set up.

BINARY NUMBER SYSTEM

The language of digital computers is binary, which is a convenient means of encoding numbers, letters, and characters. The five essential units of digital computers "talk" with one another in the same electrical language. Data and instructions are encoded by the presence or absence of electrical pulses, as indicated in figure 7-3. Here the decimal symbol 3 is encoded in its binary form—no pulse, pulse, pulse.

Many of the basic circuits in digital computers are logic circuits which provide "yes or no" answers to specific questions. These circuits may be gates which are either conducting or cut off, with the output at one of two voltage levels. Each of these voltage levels or pulses may be considered as being positive or negative with respect to the other. Normally, the output levels are referred to as digital 0's and digital 1's. Insofar as the circuitry is concerned, it is possible to use either voltage level to indicate either digit. Therefore, it is essential to the understanding of basic logic circuits that some distinction be made regarding the system of logic to be used in any specific application.



167.67

Figure 7-3.—Digital computer language a voltage pulse is a binary 1 and no pulse is a binary 0.

SYMBOLIC LOGIC

The term POSITIVE LOGIC is used to denote circuitry in which a postive level of signal voltage is used to activate the gate circuit. This is normally extended to include the idea that in a positive logic circuit, inputs of a relatively positive level will produce relatively positive output levels.

NEGATIVE LOGIC circuits operate in the same manner as positive logic circuits, except that negative inputs are used to activate the stage. Although a computer may be designed to operate with either positive or negative logic, for simplicity of explanation, the basic circuits in this chapter will be explained first using positive logic. Any circuits described which use negative logic will be designated as negative logic circuits.

Computer Symbols

Many of the basic circuits used in computers are conventional circuits applicable to general electronics. Other circuits are peculiar to logic applications. In this chapter the explanation of each basic circuit will be accompanied by a block diagram representation of the circuit, as well as a simplified schematic of the circuit.

Truth Table

A truth table is a chart used with logic circuits to illustrate the states of the input and output of a stage under all possible signal conditions. It provides a ready reference for use in analyzing the operating theory of the circuit, and is useful in developing the overall signal flow diagram.

In devising the truth table, it is necessary to know the number of inputs and their polarity. All possible states of the input are listed in column form, with a separate column for each input line. Starting with all zeros, count in digital form until all possible inputs have been covered. Then note the output for each input combination. The truth tables for most of the following circuits will serve as illustrations. Observe that the inputs and outputs are noted as relatively positive or negative levels. For a detailed discussion of truth tables, see Mathematics, Vol. 3, NavPers 10073-A.

Logic

The three basic functions needed for representation of expressions are the AND function, the OR function, and the NOT function. The meanings of these are discussed in Basic Electronics, NavPers 10087-C.

Electronic circuits which are used in mechanizing the AND, OR, and NOT functions are described in the following paragraphs. Closely related to these are the inhibitor circuit and the EXCLUSIVE OR circuit, which are also discussed.

LOGIC CIRCUITS

The basic circuits used in digital computers include many of the basic circuits used in other types of electronic equipments. These include amplifiers, timing signal generators, pulse generators, wave shaping circuits, gates, and many others. These general circuits will not be discussed in detail in this chapter. Instead, this chapter limits its coverage of basic circuits to those logic circuits which are used extensively in digital computers.

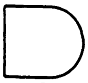
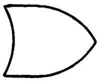
These logic circuits are the high speed electronic switching circuits that store information signals and perform logical operations on these signals. The storage circuits are discussed in a later section of this chapter. The circuits which perform logical operations (discussed in the following paragraphs) sense the input conditions and provide an output only if certain input conditions exist. They can be classified generally as gate circuits, which may employ vacuum tubes, diodes, transistors, tunnel diodes, semiconductor rectifiers, or magnetic cores.

By opening some gates and closing others, a signal may be routed over a predetermined path. The computer, when it reads input data and performs its operations, is concerned only with the arrangement of pulses of voltage or current. This is the method that designers have employed to cause the computer to perform predetermined operations, and also the method by which the computer performs those operations. The control unit determines the sequence in which the gates are to be operated, and it receives its instructions from the input data. The input data, in turn, is supplied by the programmer.

It should be recalled, from the review of Basic Electronics, NavPers 10087-C, that the symbolic operations utilized in digital computers are based on the investigations of George Boole, and the resulting algebraic system is called Boolean algebra. It is similar to the algebra with which we are all familiar, but it follows different rules.

To understand Boolean notation, the technician must ignore some of the things he has learned about the arithmetic use of the dot and plus connectives, as their use in logical operations is different from the arithmetic usage. The equations which characterize Boolean algebra are given in table 7-1. Notice that some of the rules are quite different from those of ordinary algebra. Refer to Mathematics, Vol. 3, NavPers 10073-A, or Digital Computer Basics, NavPers 10088, for additional information on Boolean algebra.

Logic diagrams may be used alone or in combinations to represent Boolean functions. The three basic diagrams are:

 (AND),  (OR), and ○ (NOT).

When the NOT function is used alone (an inverter), it is drawn with a triangle attached. ○▷. Only the circle, ○, is used when the NOT function is an integral part of an AND or OR circuit. When the NOT symbol, ○, is placed at the input of an AND or OR circuit, only that input is negated; but when the NOT symbol is placed at the output, the entire function is negated.

AND CIRCUITS

The AND circuit is similar to a coincidence circuit because it requires that all inputs occur simultaneously to produce an output. Two versions of AND circuits are shown in figure 7-4.

In figure 7-4A, two PNP transistors are connected together at the collectors and emitters to form an emitter-follower type circuit. There are two separate input terminals for the base signals. Initially both transistors are biased to saturation conduction, and nearly all of the collector voltage is dropped across R_L. Positive signals fed to the base of each transistor will cut off the respective transistor, but both transistors must be cut off in order to produce an output. When both are cut off simultaneously, the output terminal voltage will go positive.

The circuit shown in figure 7-4B is a negative logic AND circuit. With no signal applied, each

Table 7-1.— Equations of Boolean algebra

Law	Part 1	Part 2
1. Identity	$A = A$	$\bar{A} = \bar{A}$
2. Intersection	$A \cdot 1 = A$	$A \cdot 0 = 0$
3. Union	$A + 1 = 1$	$A + 0 = A$
4. Complementary	$A\bar{A} = 0$	$A + \bar{A} = 1$
5. Idempotent	$AA = A$	$A + A = A$
6. Commutative	$AB = BA$	$A + B = B + A$
7. Associative	$A(BC) = ABC$	$A + (B+C) = A + B + C$
8. Distributive	$A(B+C) = AB + AC$	$A + (BC) = (A+B)(A+C)$
9. Absorption	$A(A+B) = A$	$A + (AB) = A$
10. DeMorgan's Theorem	$\overline{(AB)} = \bar{A} + \bar{B}$	$\overline{(A+B)} = \bar{A}\,\bar{B}$
11. Double Negative	$\overline{\overline{A}} = A$	
12. Unnamed Laws (2)	$A(\bar{A}+B) = AB$	$A + \bar{A}B = A + B$
13. Unnamed Law	$\bar{A} + AB = \bar{A} + B$	$\bar{A} + A\bar{B} = \bar{A} + \bar{B}$

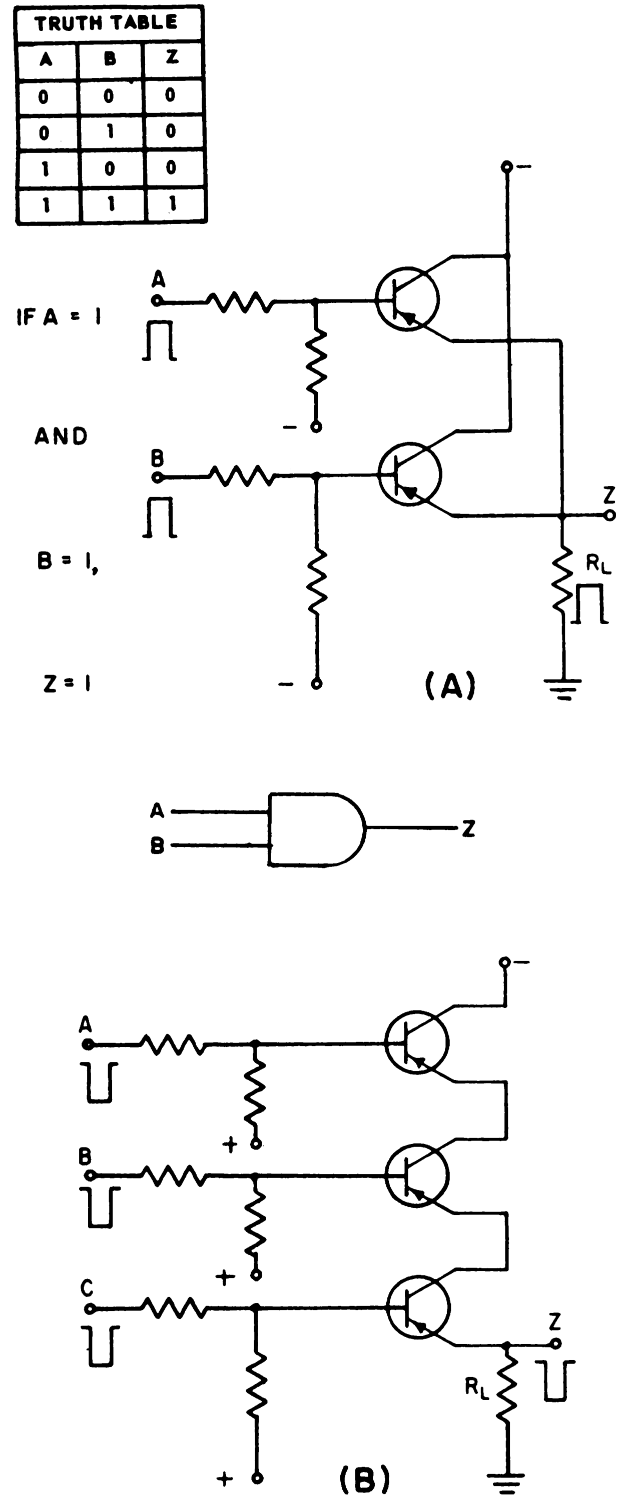
167.752

transistor is cut off. During operation, all transistors must be conducting together. If any one or more of the transistors remains cut off, there is no current path through the series connected emitter-collector circuits. If all transistors are driven into conduction (by negative signals applied to the bases), the output at the emitter terminal will go negative.

OR CIRCUITS

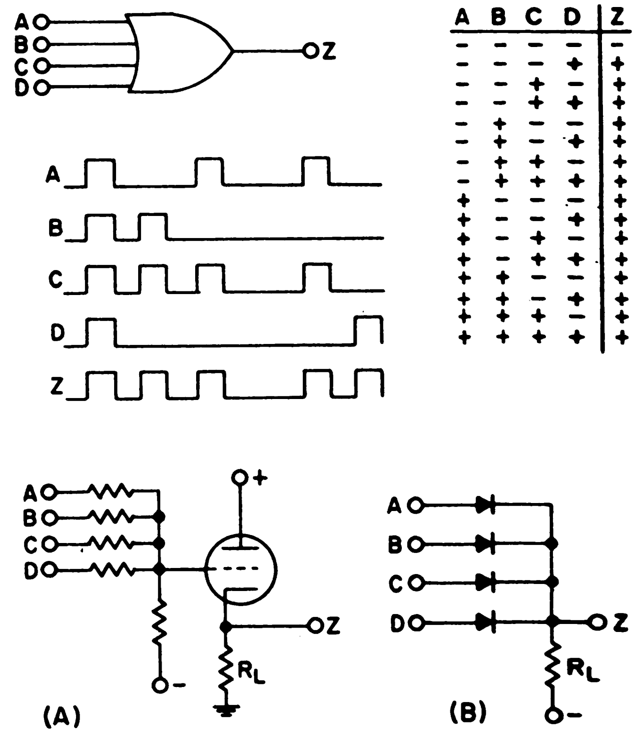
An OR circuit is a logic circuit having two or more inputs and producing an output if any one or more of the inputs are placed in the required signal state. Figure 7-5 shows two types of OR circuits.

Note in the block symbol, four inputs are illustrated. This is not necessary—many OR circuits are used which have only two inputs. In an OR circuit, any practical number of inputs may be used. The truth table in this figure also illustrates that a two-level gate with 4 inputs may have 16 different input signal combinations (2^4). The waveform drawing does not show all



TRUTH TABLE		
A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

12.134(167)
Figure 7-4.—AND circuits. A. Positive logic AND: B. Negative logic AND.



A	B	C	D	Z
-	-	-	-	-
-	-	-	+	+
-	-	+	-	+
-	-	+	+	+
-	+	-	-	+
-	+	-	+	+
-	+	+	-	+
-	+	+	+	+
+	-	-	-	+
+	-	-	+	+
+	-	+	-	+
+	-	+	+	+
+	+	-	-	+
+	+	-	+	+
+	+	+	-	+
+	+	+	+	+

12.133(167)
Figure 7-5.—OR circuits. A. Vacuum tube; B. Diode.

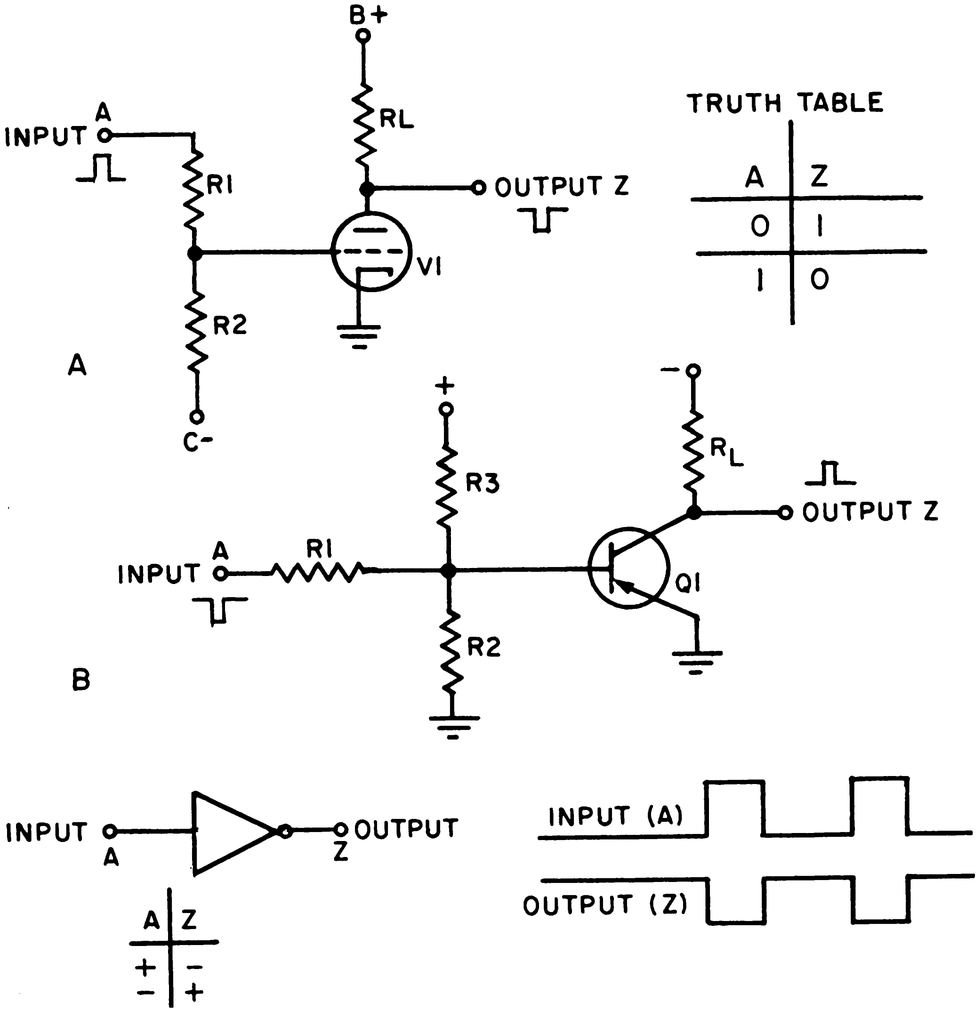
possible input combinations, but enough combinations are shown to convey the idea that with any positive input, a positive output will result.

The vacuum tube in the circuit shown in (A) is biased to cutoff when there is no signal applied. The inputs are each fed through a resistor to the grid of the tube. The resistor in the signal path decreases the interaction between the individual input lines. A positive signal applied to any one or more of the input leads causes the tube to conduct, and a positive signal appears at the cathode.

The positive logic diode OR circuit shown in (B) can be examined using the logic table as shown. When any one or more of the inputs receives a positive signal, the diode receiving that input conducts. A signal is impressed across R_L, resulting in a positive waveform at the output.

NOT CIRCUITS

The NOT circuit, also known as an inverter, is nothing more than a normal gate amplifier stage that produces an inversion (negation) of the input signal and has unity gain. Figure 7-6 illustrates two NOT circuits.



12.135(167)

Figure 7-6.—NOT circuits. A. Vacuum tube circuit; B. Transistorized.

In the vacuum tube circuit shown in (A), the triode is biased beyond cutoff.

A positive input pulse causes the tube to conduct, and the output voltage level changes to a relatively negative value. A negative logic vacuum tube NOT circuit in the same configuration would be biased for heavy conduction when no signal is applied, and negative inputs would be used to cut the tube off. The voltage divider (R1 and R2) in the grid circuit limits the circuit gain to unity.

In the PNP transistor circuit shown in (B), the transistor is biased to cutoff by the divider (R2 and R3), making the base positive with respect to the emitter. The input signal is divided by R1 and R2 to make circuit gain unity. Note that the input signal must be negative to cause conduction; therefore, this circuit represents a negative logic NOT CIRCUIT. The same truth table is valid for this circuit, but the polarity of the input and output waveforms must be reversed.

Note that any circuit which inverts the signal and has unity gain falls under the definition of a NOT circuit. One common device used in this manner is the unity transformer.

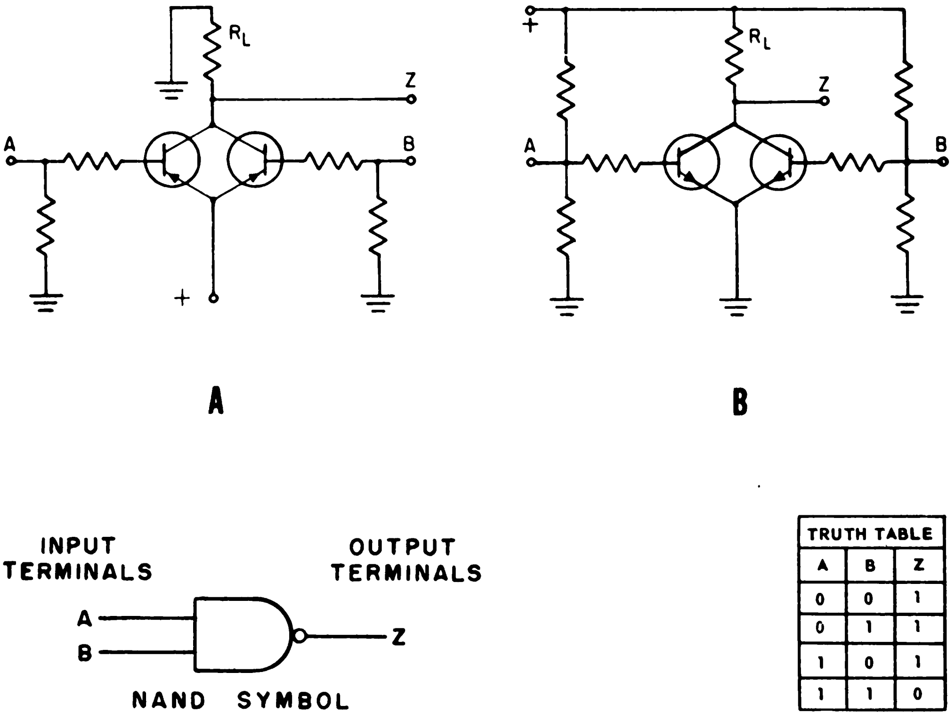
NAND CIRCUITS

Two NAND (NOT AND) circuits are shown in (A) and (B) of figure 7-7. Both of these circuits combine the AND function and the NOT function.

In (A) the PNP transistors are biased for saturation conduction in the absence of signals. If positive signals are applied simultaneously in both bases, both transistors will cut off the AND function. When cutoff occurs for both transistors, the collector voltage (output) goes relatively negative. This signal inversion is the NOT function.

In (B) the NPN transistors are also statically biased for saturation conduction. When both transistors are cut off by coincident negative signals, the output voltage from the collector is relatively positive. This is a negative logic NAND circuit.

Comparision of these circuits illustrates the similarities and the differences between positive



TRUTH TABLE

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

67.90(167)

Figure 7-7.—NAND circuits: A. Positive NAND: B. Negative NAND.

nd negative logic circuits, and the AND, OR, and NOT functions. (1) In transistor logic circuits, f the output signal is taken from the emitter, here is no inversion of the signal; if the output s taken from the collector, the circuit is capable of performing the NOT function. (2) In series connected transistors, all transistors must conduct if the output signal is to be the result of conduction. (3) If the transistor is cut off under no-signal conditions, a definite polarity is required to cause conduction; if the transistor is conducting, the opposite polarity input is required in order to cut it off. (4) PNP and NPN transistors react differently to the same conditions of biasing and signal.

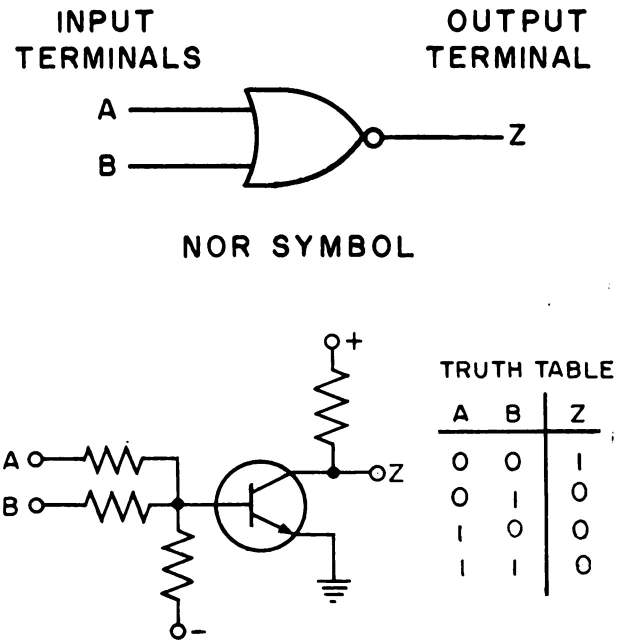
When studying any specific computer circuitry to determine its theory of operation, these four factors must be taken into consideration. Refer to the circuit shown in figure 7-7 (A). As shown, it is a positive logic NAND circuit. By moving the output resistor (R_L) to the emitter circuit, the NOT function is removed, and the circuit becomes a positive logic AND circuit identical to (A) in figure 7-4. If the PNP transistors are biased at cutoff, negative inputs are required to produce conduction. However, since conduction of either transistor would produce an output, the circuit becomes an OR circuit (or a NOR, depending on the connection of the load resistor).

NOR CIRCUIT

Figure 7-8 shows a transistor type OR circuit that also includes the negation function of a NOT circuit. A circuit that performs both of these logic functions is sometimes called a NOR (NOT OR) circuit.

With no input signals applied, the NPN transistor is biased to cutoff by the reverse bias between emitter and base. A positive input pulse causes saturation conduction of the transistor, producing a negative output pulse at the collector. A truth table for this circuit shows that the output is negative when any of the inputs are positive.

Similar circuits could be arranged for negative inputs by biasing an NPN transistor to saturation, or by biasing a PNP transistor to cutoff.



A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

167.113

Figure 7-8.—Transistor NOR.

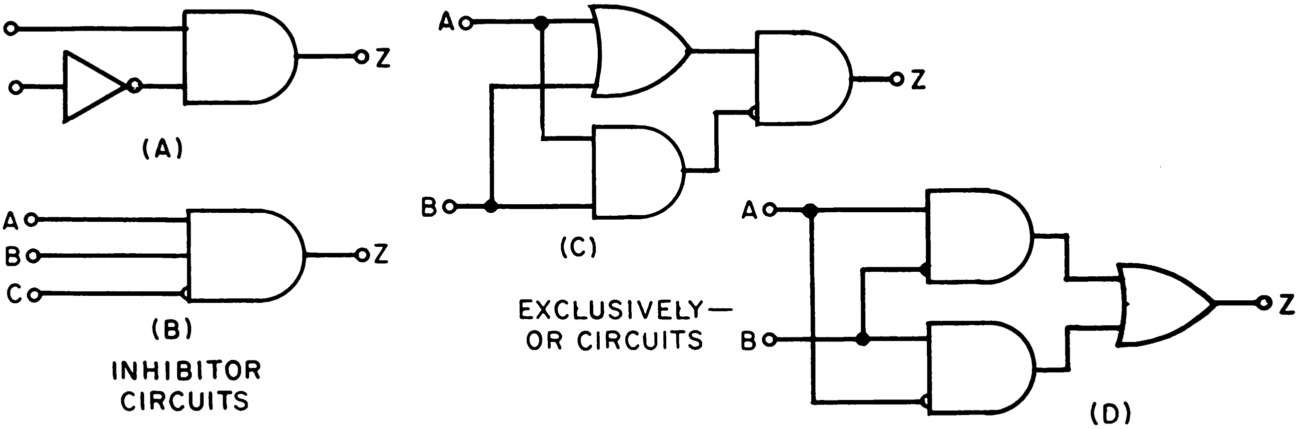
INHIBITOR CIRCUITS

The combination of an AND and a NOT circuit, in which the NOT circuit is inserted between one input terminal and the AND circuit, is called an INHIBITOR circuit. Figure 7-9 (A) shows the functional arrangement of the combination; (B) shows the common block diagram symbol, where the inhibit signal input to the block is shown by a small half-circle. The NOT and the AND circuits can take the form of any of the circuits previously discussed; the only requirement of the NOT circuit is that it invert the signal. This circuit produces an output signal under the following conditions only: All of the regular inputs are applied, but no input signals is applied to the inhibit terminal.

EXCLUSIVE—OR CIRCUITS

An EXCLUSIVE—OR circuit is a combination of circuits with two input signal terminals, but which produces no output when two signal of like polarity are applied simultaneously. However, if only one input signal is applied, an output signal is produced.

Two combinations of basic circuits that can be used to form an EXCLUSIVE—OR circuit are shown in (C) and (D) of figure 7-9. For the circuit in (C), input signal A will pass through the OR and INHIBITOR circuits to the output if no signal from the AND circuit reaches



167.114

Figure 7-9.—Inhibitor and exclusively -OR logic circuits.

the inhibitor terminal. But if a signal is applied to input terminal B, causing the AND circuit to operate, a signal will reach the inhibit terminal and prevent any output.

In (D) two simultaneous input signals will prevent an output from both INHIBITOR circuits, and therefore from the OR circuit.

Signals A and B are alike and occur simultaneously to produce no-output.

This type circuit can be used to compare two pulse trains, and to produce an alarm signal output when the two trains are not identical. In this manner, two signal trains that are supposed to be indentical can be monitored simultaneously, and any error can be used to activate a warning circuit.

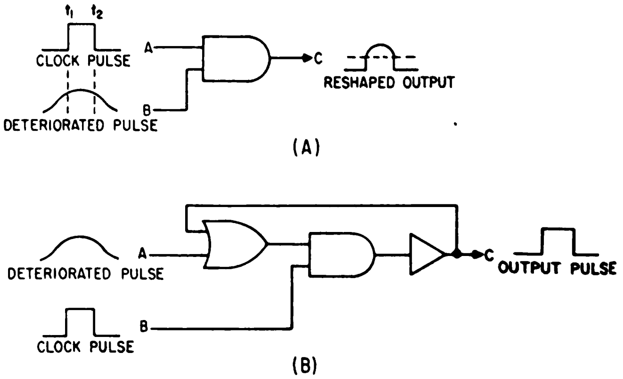
PULSE RESHAPING CIRCUITS

Although reshaping circuits do not, strictly speaking, perform a logic function, they use circuits that are classed as logic circuits. Their function is the reshaping of pulse trains that may have deteriorated in shape and amplitude beyond further usability. As pulse trains pass through various circuits of a computer, the rise and fall times of the pulses usually increase; the amplitude may decrease; and the pulses are delayed in time.

The clock pulses, which are usually available at several points in the computer, are used with a reshaping circuit to restore the shapes of numerical or instructional information pulses within the computer.

If the information pulses to be reshaped occur at the same time as an available clock pulse, a simple AND circuit can be used to reshape the pulse. Figure 7-10 (A) shows clock pulses and deteriorated pulses applied simultaneously to terminals A and B, respectively, of an AND circuit. In a properly designed circuit, the output is produced only during the time interval t_1 to t_2. The rounded top of the output pulse can be clipped in a succeeding amplifier stage.

Instances will occur when the deteriorated pulses to be reshaped are no longer in time synchronization with the clock pulses. In these cases, the circuit shown in figure 7-10 (B) can be used to reshape the pulses.



AQ.539

Figure 7-10.—Block diagram of pulse reshaping circuits.

The deteriorated pulses and clock pulses are applied to terminals A and B, respectively. The deteriorated pulses pass through the OR circuit and, together with the clock pulses, cause an output from the AND circuit during the portion of the time that they occur simultaneously.

If there were no regenerative (positive) feedback from the amplifier output, the output would be representative of only the overlap time of the deteriorated and clock pulses. However, the positive feedback and the clock pulse keep the AND circuit functioning, producing an input to the amplifier until the clock pulse ends. This produces an output pulse that is identical to the clock pulse. Note that this circuit allows a pulse that is not in exact time sequence with a clock pulse to be reshaped, but there must be some overlap in the duration of the two pulses.

ARITHMETIC CIRCUITS

An automatic digital computer is a vastly complicated machine with a great many electronic circuits. Although the number of circuits is high, the variety is small. That is, it consists of a large number of a few types of gate circuits. Many of the types found in the arithmetic unit were discussed in the preceding section as logic circuits. An additional type of logic circuit not previously discussed, the Eccles-Jordon multivibrator, known as a flip-flop (FF), is in wide use in the binary counters and the registers of the control and arithmetic units.

Next to be considered is how the FF and other logic circuits are combined to form counters, registers, and adders; and how they perform the temporary storage, addition, subtraction, multiplication, and division functions of the arithmetic unit.

FLIP-FLOPS

The modified Eccles-Jordan multivibrator is the circuit used, in conjunction with other circuits, for counting. It is a two-state oscillator that remains in either of its two conditions until a pulse is received to flip it to the opposite condition. The output, if taken from the plate of one tube, will be a positive voltage representing a 1 in one condition and a low voltage representing a 0 in the other condition. Each pulse input to the stage will flip it to the opposite condition, so two pulses are required at the input to produce one pulse at the output.

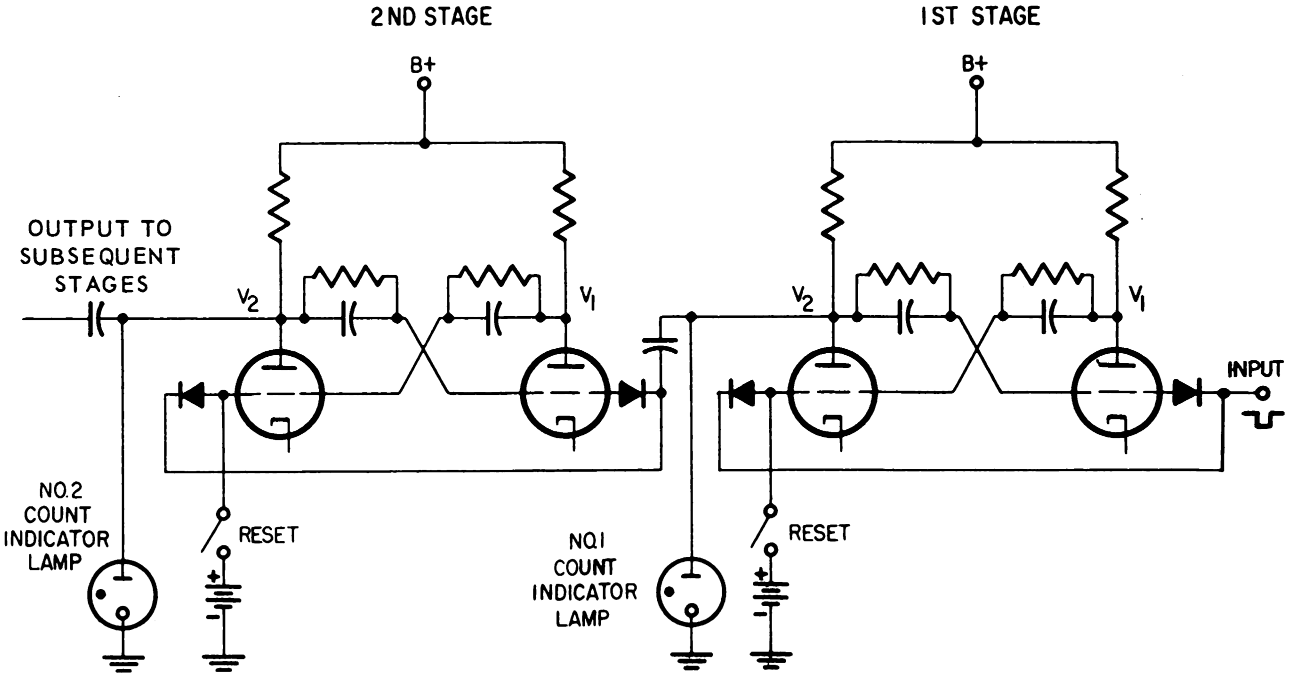
The simplified flip-flops in figure 7-11 are arranged to show the basic arrangement of counters. Should you require a refresher on the theory of the plate coupled multivibrator, refer to Basic Electronics, NavPers 10087-C.

Counting by flip-flop is possible because of the characteristic that requires two pulses in to produce one pulse out. In the figure, note that the input to the counter chain is on the right side of the figure. This arrangement is used because the indicator lamps of each stage will be read as binary numbers, with the first stage lamp indicating a decimal 1, the second stage lamp indicating a 2, and subsequent stages indicating, 4, 8, 16, and so forth. If the lamp in the second stage is lighted and the lamp in the first stage is not lighted, the binary indication is 10, or decimal 2. If both lamps are lighted the binary number is 11, or decimal 3. Additional stages are necessary to count a higher number than three, and each of these additional stages from the input represents a power of two.

Note also that the grid of each tube labeled V2 has a reset provision with a positive voltage that is applied by closing the switch. Before any counting is begun, all the V2 tubes in the chain are caused to conduct by a momentary closing of the reset switch, and all indicator lamps register 0. This is the reset condition.

The grids of both tubes in each stage are jumped together so that any negative signal applied appears on both grids simultaneously. The diodes in the grid inputs prevent a positive signal from reaching the grids. They respond only to negative pulses.

Assume that the circuit has been reset so that all V2 tubes are conducting. In this state the plate voltage is too low to the light the neon lamp, and all lamps register 0. The first negative pulse applied to the inputs of V1 and V2 flips the circuit to the opposite condition; V1 now conducts, V2 cuts off, and its plate voltage rises and lights the lamp to indicate 1. The positive rise of voltage is capacitively coupled to the second stage, but the diodes prevent the positive pulse from having any effect. Reading the two indicator lamps after the first pulse has been applied produces binary 01, meaning a count of one. The second negative pulse that arrives causes the first stage to flop back to the reset state; V1 cuts off; V2 goes into conduction, its plate voltage drops, its lamp goes out; and the negative pulse is coupled to the second stage. This negative pulse flips stage No. 2 to its opposite state and lights its lamp, indicating a 2. The lamps now register binary 10,


2ND STAGE
1ST STAGE
B+
B+
OUTPUT TO SUBSEQUENT STAGES
V2
V1
V2
V1
INPUT
NO.2 COUNT INDICATOR LAMP
RESET
NO.1 COUNT INDICATOR LAMP
RESET

167.112

Figure 7-11.—Basic flip-flop counter.

which is decimal 2. Note that two pulses were required at the input to produce one pulse out.

In late-model computers the flip-flop circuits use transistors, and a long chain of such stages can be built into a small space. Each additional stage makes provision for a higher counting capability. Each succeeding countdown circuit, as the flip-flop is sometimes called, "counts" in the same manner, or scales by two. Each additional stage also scales by two; a two-stage flip-flop as shown in the figure scales by four; a three-stage unit will scale by eight; a four-stage unit will scale by 16, and so forth.

The same circuit, with only slight modification, could be used to count positive inputs.

Figure 7-12 (A) shows a transistorized FF circuit. Other devices that are capable of two states of operation (for example, tunnel diodes or magnetic core coils) can also be used in the construction of FF's. A block diagram symbol commonly used to represent the FF in computers is also shown in figure 7-12 (B).

A reset input signal sets the stage to a 0 condition or clears the previous 1 count if one was present. If several stages in a counter are cascaded, the reset signal is generally connected to all stages; and they are all reset to 0 simultaneously.

The complement (trigger) input is applied to both halves of the FF, and a signal causes the stage to change from a 0 to a 1, or vice versa. In registers, the complement signal is generally a single pulse that is applied to all stages simultaneously. It produces the 1's complement of the binary number held by the register. In a counter, the complement input of only the first stage could be used as the signal input for the pulses to be counted. The signal and complement inputs can also be applied symmetrically in the plate or collector circuits.

In case the stage is in the 0 state, the set input signal flips it to the 1 state. In most counters, instead of using the complement input, the reset and set inputs of the first stage are paralleled and used for the input signal.

The three inputs use negative signals, to cause a change of state in the FF. It is sometimes desirable to design the stage for positive signals, but a FF stage can be more precisely controlled if it is switched from a state of heavy conduction than from a cutoff state. Note that

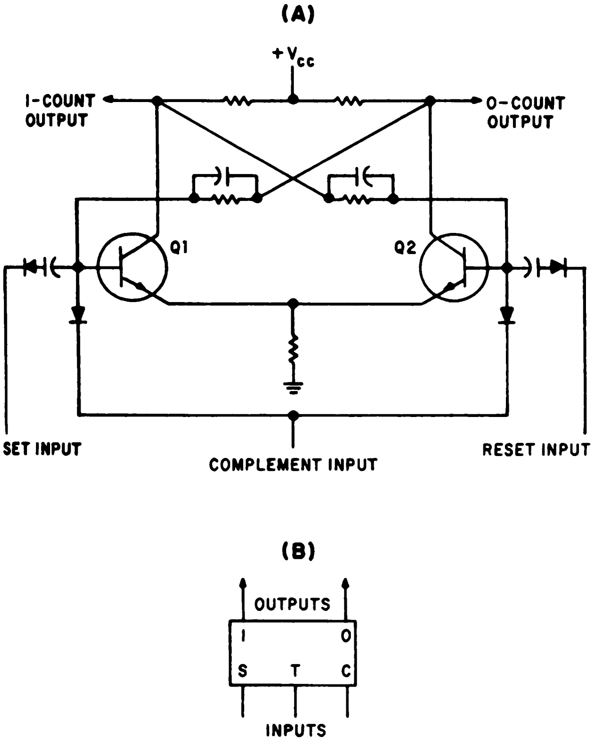


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Figure 7-12.—(A) FF using transistors; (B) FF block diagram symbol.

each stage counts to a scale of 2, but indicates a maximum count of only 1, a 0 would be indicated for a second input pulse.

TYPES OF INPUT

Binary words are fed into the logic and arithmetic circuits in either of two different forms, serial or parallel, or in a combination of the two. In serial form the bits follow one another sequentially on a single input line. In parallel form, all the bits of the word are applied simultaneously over a number of paths equal to the number of bits in the word. A bit is a binary 1 or 0. A binary word is a series of bits arranged in a sequence that has meaning to a computer. Figure 7-13 illustrates both methods of input.

Each method has advantages and disadvantages. The method used in a particular computer depends on whether extremely high speed arithmetic operations are needed or whether economy and machine simplicity are more important. A machine with serial operation is much more economical. For example, in the case of a counter or register, a word representing decimal 15 (1111 in binary) can be handled by four flip-flops; and, as will be shown later, there is no limit to the word length a serial adder will handle.

A parallel counter or register for handling binary 1111 also requires four flip-flops, but its speed of operation is four times faster than the speed of a serial counter or register. However, 30 flip-flops would be required for a parallel 30-bit word. In a parallel adder, a separate adder is required for each bit of both the addend (the number that is to be added to another) and augend (the number to which another is to be added). However, the addition is completed in the same time a serial adder requires to add one-bit addend and augends. The complexity of a parallel arithmetic unit over a serial unit is multiplied by the word length.

REGISTERS

A register is a place or device in which information is held, stored, preserved, or remembered. It provides temporary storage of a binary word during computation. Registers are composed of flip-flops (FFs) and are generally found in the control and arithmetic units of digital computers. There may be several in a large computer; however, a simple arithmetic unit may contain only one or two. The number depends on the amount and variety of other storage facilities that are included. It is also

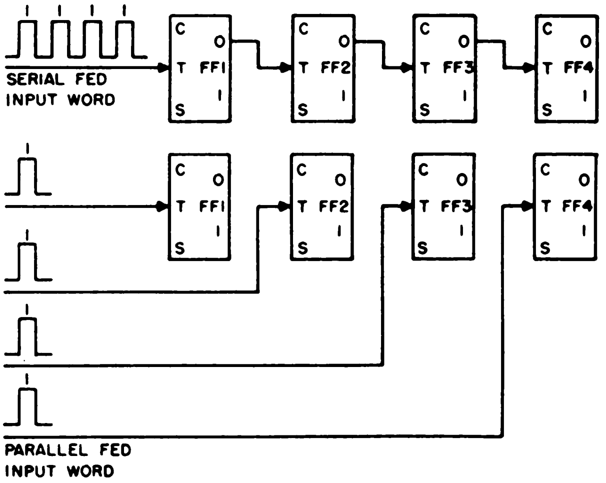

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Figure 7-13.—Examples of serial and parallel inputs.

somewhat dependent upon the speed with which the computer operates. A relatively long time is required to readout a word from a magnetic drum memory; a shorter readout time is possible with magnetic core matrix type memory units. Generally, one or more arithmetic registers can be used to advantage in speedup computation.

Remember that a word is a group of pulses; each pulse, or lack of one, represents a bit; each bit represents a binary digit of 1 or 0. The chain of bits can be almost any length. This group of pulses at the input unit can represent instructions, constants, and/or variables for the problem. In the actual arithmetic circuits, the pulse chains that represent the constants and variables for the problem are present. The instruction portion of the word is used to program the computer.

Storage Register

A storage register stores a word temporarily. Storage registers consist of a group of FF's that store the maximum word length expected; they operate in the same fashion as counter FF's. Figure 7-14 represents a storage register which can handle a four-bit word. The lower group of FF's comprise the register, and the upper group forms an associated counter. Between the two is a group of AND circuits. (Note that the input to the counters is in serial form and the input to the register is in parallel form; therefore, it also forms a serial to parallel converter for the word. The counter is included in the set because of this function as a converter.)

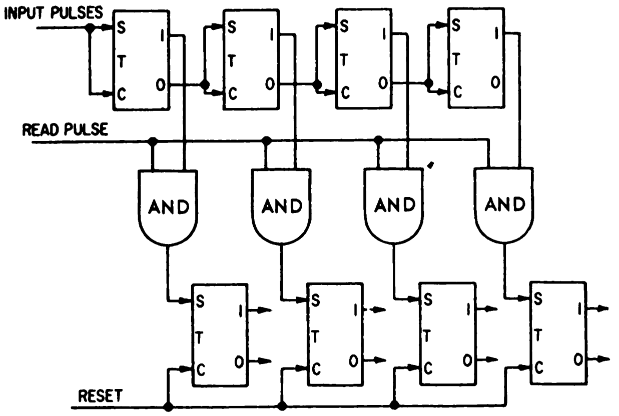

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Figure 7-14.—A four-bit-register and associated counter.

First, the word is applied to the counter. Later a read pulse is applied to the AND circuits. If the read pulse and the voltage at the 1 output of a particular counter FF agree in voltage levels, a 1 pulse is transmitted to the corresponding register FF. No signal is transmitted to a register FF if the 1 output of the corresponding counter FF is at a 0 voltage level or, in any case, until there is a read pulse applied.

Each register FF can store a single bit, representing a 1 or 0. Note that at the same time a 1 is represented by a 1 level of voltage at the 1 output terminal, a 0 voltage level is represented by the 0 output terminal. The output from the lower FFs (fig. 7-14) might be applied to the augend or addend terminals of a parallel adder circuit, the other word being supplied by similar means. If both the 1 and 0 leads are connected to other circuits, the condition is known as "double lead transfer" of information.

An extra bit is included in an information word to indicate the sign of the binary number. A three-bit word such as +110 would be fed into the counter or register as 0110, where the first 0 would indicate a positive number. A negative number would be 1110. Therefore, the circuits that handle signed words must have an extra FF to handle the sign bit.

A storage register and serial-to-parallel converter that does not use an associated counter is shown in figure 7-15. Delay lines (D) are used here to provide the conversion from serial to parallel. Each delay line introduces a delay equal to the input pulse spacing. Therefore, the first input pulse (the one on the left in the pulse train) arrives at A4 at the same instant that the last bit pulse is applied at A1. The input pulse spacing is the same as that of the clock pulses for serial form. Therefore the read pulse could be taken from the clock, but it must not be applied to the AND circuits before the last input pulse is applied to A1. With the exception of the delay line feature, the circuit is the same as the one in figure 7-14.

Shift Register

A shift register is a storage register in which the stored number can be shifted left or right with a shift pulse. (See fig. 7-16.)

The shift pulses are applied continually, using the same spacing as the bits of the word. Since the FF would be upset if two pulses

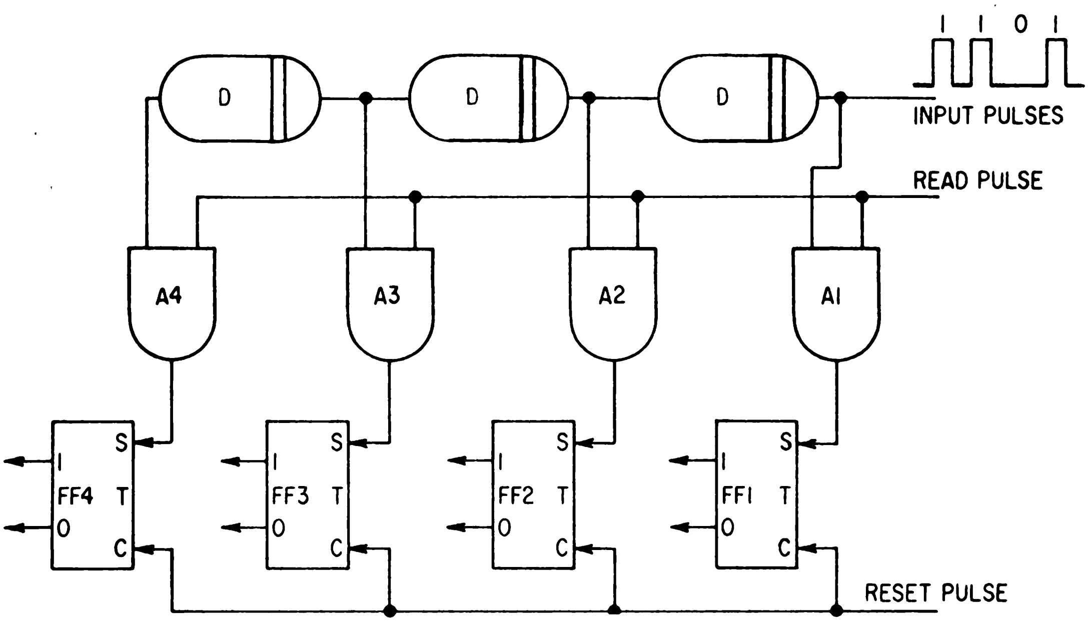

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Figure 7-15.—Storage register using delay lines.

occurred simultaneously, the shift pulse is applied midway between bit pulses. The stages are so coupled that any particular FF is set to a 1 state only if the preceding one was reset to 0 by the shift pulse. The delay lines (which may be RC circuits) have a delay that is only a small portion of the spacing between pulses. The operation of the shift register is explained in the following paragraphs.

Assume that the binary word 1101 (decimal 13) is to be stored and that all FF's have been reset to 0. The first 1 bit is applied and sets FF1 to 1. This does not affect FF2. A shift pulse then occurs that resets FF1 to 0; and FF2 receives, after a short delay, a pulse from FF1 that sets it to 1. Then the second 1 bit is applied to FF1, setting it to 1 again. Now both FF1 and FF2 are set to 1; and another shift pulse occurs, resetting them to 0. Shortly thereafter, FF2 and FF3 are set to 1. The next bit in the word is a 0 and has not effect on FF1. The following shift pulse resets FF2 and

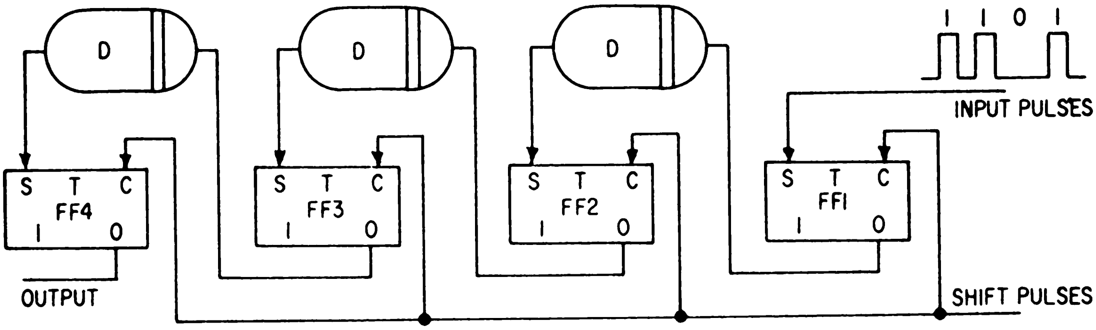

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Figure 7-16.—Shift register.

FF3 to 0; later, FF3 and FF4 are set to 1. FF1 and FF2 now read 0. The last bit sets FF1 to 1. Shift pulses are stopped at this point, and binary word 1101 has been stored.

The application of four additional shift pulses causes the stored word to be read out the left side of the register. The contents can be read out to additional FF stages, to the memory unit, or to adder circuits. The output might also be returned to the input, through pulse reshaping amplifiers, to form a dynamic (circulating) type register.

A digital computer can add or subtract almost indefinitely, and with lightning speed. For this speed to produce meaningful results, the computer must be supplied with complete instructions before each operation. The speed, accuracy, and versatility of the computer are determined by the type of instructions provided and the manner in which they are given. These instructions will at times be specific information, such as a number that represents some item of data, and at other times will be a number that represents an instruction. For instance, the program may instruct the computer to carry out a sequence of operation as follows:

1. Select a specific item from a specific location of a memory channel and transfer it to the arithmetic unit.
2. Select another item from some other memory channel and transfer it to the arithmetic unit.
3. Compare the two numbers.
4. Place the larger of the two numbers in a specified address in a specific memory channel.

The function of the control circuitry of a digital computer is to intepret the instruction of the program and to send control signals to the other sections of the computer to peform these instructions. Control circuitry includes the decoder networks and a control generator for producing the control signals, which are timed for proper operational sequence and sent to the other sections of the computer. For example, the instruction words are entered into the input section and then sent to the control section for decoding.

For read-into-memory instructions, the instruction is decoded, and the resultant control signals are sent by the control generator back to the input section and memory to execute the instruction. Similarly, when an add instruction is sent by the input section to the control section, a control signal is generated that causes data to be read from memory and added into the accumulator in the arithmetic section. Control signals to the arithmetic section tell this section to peform the actual addition in the accumulator.

Read-out instructions decoded by the control section are used to produce signals that control data, from either the memory or the arithmetic section, to be sent to the output section. A read-out instruction, therefore, causes the control section to generate control signals to the output section to accept data from these sections and transfer the data to the output unit.

From the above general discussion, you can see that the control section must time the many control signals developed and send them in proper sequence to the other sections of the computer. For example, assume the program contains the following instruction word:

Location	Operation Code		Memory Address
115	05	Cla	350

During the program run, a control signal is sent to memory control to select memory location 115 and read out its contents (the instruction word). The operation code 05 tells the control section that the clear and ADD operation (Cla) is to be performed on the data stored in memory address 350.

The control section sends signals to memory location 350 and to the accumulator. The signals to the accumulator clear it of any previous contents, while the signals to memory location 350 read out the data content of this address. Other signals to the accumulator cause the data from memory to be stored in the accumulator, thereby completing the CLEAR AND ADD operation.

As stated before, the instruction data that is stored in memory as part of an instruction word is used to develop control signals that time the sequence of operations and tell the other sections of the computer what to do. In the example above, the operation code 05 is used to illustrate the timing and sequence of operation for a clear and add instruction. The mechanization of this instruction is shown in figure 7-17.

Operation code 05 (binary 101) is stored in the three-stage flip-flop decoding register. The three AND circuits are used to produce the control signals that initiate the instruction. Clear and add instruction 101 stored in the decoder register causes the 1, 0, and 1 outputs

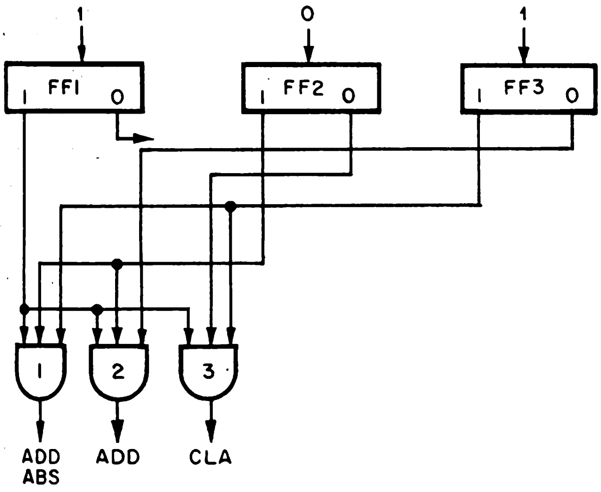

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Figure 7-17.—Mechanization of an instruction word.

of the FF1, FF2, and FF3 circuits to be ANDed at the AND 3 circuits, to produce the clear and add control signal. This signal is used to clear the accumulator and to gate the memory location for the data in the instruction word. The signal is also used to trigger another control signal that allows the extracted memory data to be added to the accumulator. The timing for these two operations is controlled by CLOCK pulses. These pulses are produced by the clock generator which operates at a set frequency. It is analogous to the rpetition rate generator in a radar. With every clock pulse, the various circuits that control the performance of these operations are gated so that the proper operational sequence is established. The control signals from the other AND circuits are produced when corresponding operation codes are stored in the three-stage flip-flop register. (The number of stages is determined by the number of instructions the computer is able to perform.)

The program portion just described is a simple example used to show how a programmer talks to a computer.

The Accumulator

Storage operations are performed in the accumulator. Basically, it consists of a memory section called a register (discussed later in this chapter) and is used with an adder. The register is a group of flip-flop and memory elements that route and store data. Adders are explained shortly. The A-register has two purposes; it furnishes the stored augend to the adder, and stores the sum of an addition operation. See fig. 7-18.)

In this connotation, the ''augend'' is the subtotal. In each progressive addition, the total of the previous addition is fed to the adder (as the augend), and is then combined with the new data to furnish a new total which is stored in the A-register. For example, the A-register holds a number, say 4, and it is to be added to another number, say 3, then both the 4 from the A-register and the 3 from the addend register are sent to the adder. The sum of the addition, a 7, is sent to the A-register and remains until more data is to be added to it. Thus, the A-register accumulates data for arithmetic operations.

Clock Pulses

An idea which is basic to most digital computers is that of a uniform rate of counting (synchronous operation). To provide for this feature, a CLOCK, or master timer, is employed. This circuit produces or controls the rate of timing pulses. The interval between the pulses determines the period of time during which an event can occur. If a signal is delayed for a number of pulse intervals and then fed back to the input of an AND circuit, that signal

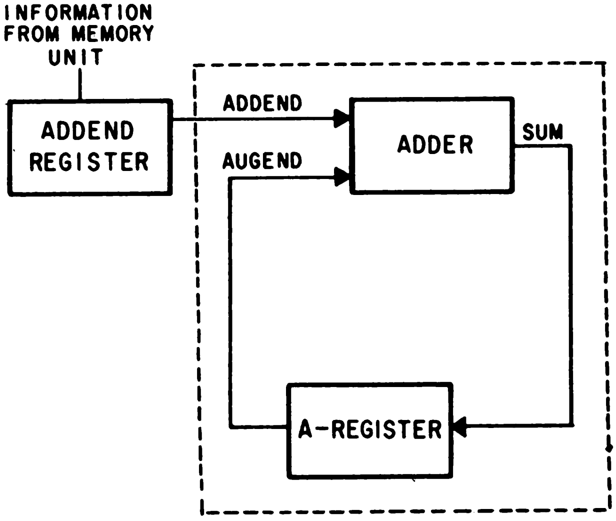

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Figure 7-18.—The accumulator.

will be continuously regenerated, and may be used to store data bits (binary digits) according to the length of the delay. Since the AND circuit will produce an output only when both input signals are present, the repetition of the pulse permits the transfer of data during that interval. The delay may be of any convenient length, and may be used to store any number of digits.

ADDERS

Adders in digital computers use combinations of AND, OR, NOT, and INHIBITOR circuits for performing addition. When adding numbers, it is often necessary to CARRY a number to the next column. For example,

$$\begin{array}{r} ① \\ 45 \\ +\ 19 \\ \hline 64 \end{array}$$

It is the carry function of arithmetic (the 1 encircled) that necessitates complex circuits in computers. When it is not necessary to carry, a simple OR circuit could easily add numbers, for it has an output whenever pulses appear at either or both inputs.

A binary word appears as a train of pulses with spaces to indicate 0's. In an adder, a pulse train applied to one input will be added to a pulse train applied to another input. In figure 7-19(A) the OR circuit has faithfully produced an output pulse each time a pulse appears at either input—but the output answer is not the correct sum of the two input binary words. The pulse train at input No. 1 is binary 101101, which is 45 in decimal notation; at input No. 2 the binary 010011 is decimal 19. Adding 45 + 19 = 64, which should appear as binary 1000000 in the output. The error is caused by the fact that this circuit cannot "carry" a digit. Additional circuits must be used with the OR circuit to provide the means of CARRYING in addition.

One of the circuits that must be discussed in connection with adders is the delay circuit. The delay circuit functions much like a delay line in a radar. In a computer it delays a pulse train for the duration of one pulse—that is, all the pulses in a train advancing from left to right are moved one place to the left. Thus, the binary 001 applied to a delay circuit becomes 010 in its output. The delay circuit permits the carry function of arithmetic in adders. It is used with a combination of OR, AND, and NOT circuits to make up a full adder circuit. A full adder consists of two half adders and a delay line. A half adder is shown in 7-19(C).

Note that a half adder is made up of some circuits already discussed. In schematic presentation the half adder would appear as one block, and it would be understood to contain the circuits shown in (B), with the previous carry included. Such a circuit (the half adder) is seldom used alone, but is combined with another half adder and a delay line to form a full adder, as will shortly be shown.

Circuit (B) shows why the half adder will not perform addition properly. Both inputs to the AND circuit experience a 1 simultaneously with the first digit applied, and an inhibiting pulse is produced. At the inhibitor's input, the inhibiting pulse from the AND circuit prevents an output when the first 1 digit from the OR circuit is applied, and the output is not a correct total of the binary inputs (001 and 101).

Binary addition is performed as follows when a carry is involved:

$$\begin{array}{r} ① \\ 001 \\ 101 \\ \hline 110 \end{array}$$

In the first column a 1 is to be added to a 1—the sum is 0 with a 1 carry (the 1 carry is shown encircled over the second column). Adding the 1 carry to the two 0's in the second column produces a sum of 1, with no carry. In the third column a 1 added to a 0 produces a sum of 1. Thus, 110 is the correct sum of the two inputs to the half adder; but because the inhibiting pulse of the carry is in the first place instead of the second place, a false sum of 100 is produced. Another half adder and a delay line that shifts its digits one place to the left will correct this situation. Note in circuit (C) that two outputs are produced from the half adder—one is a sum and the other is a carry. Circuit (D) utilizes these two outputs in combination with a delay line and a second half adder to complete a full adder.

The first and second half adders in the figure are identical and contain the circuits shown in circuit (B). Circuit (D) shows the half adders as blocks combined with a delay line. Note that the delay line shifts the carry from the first half adder one place to the left—this means that

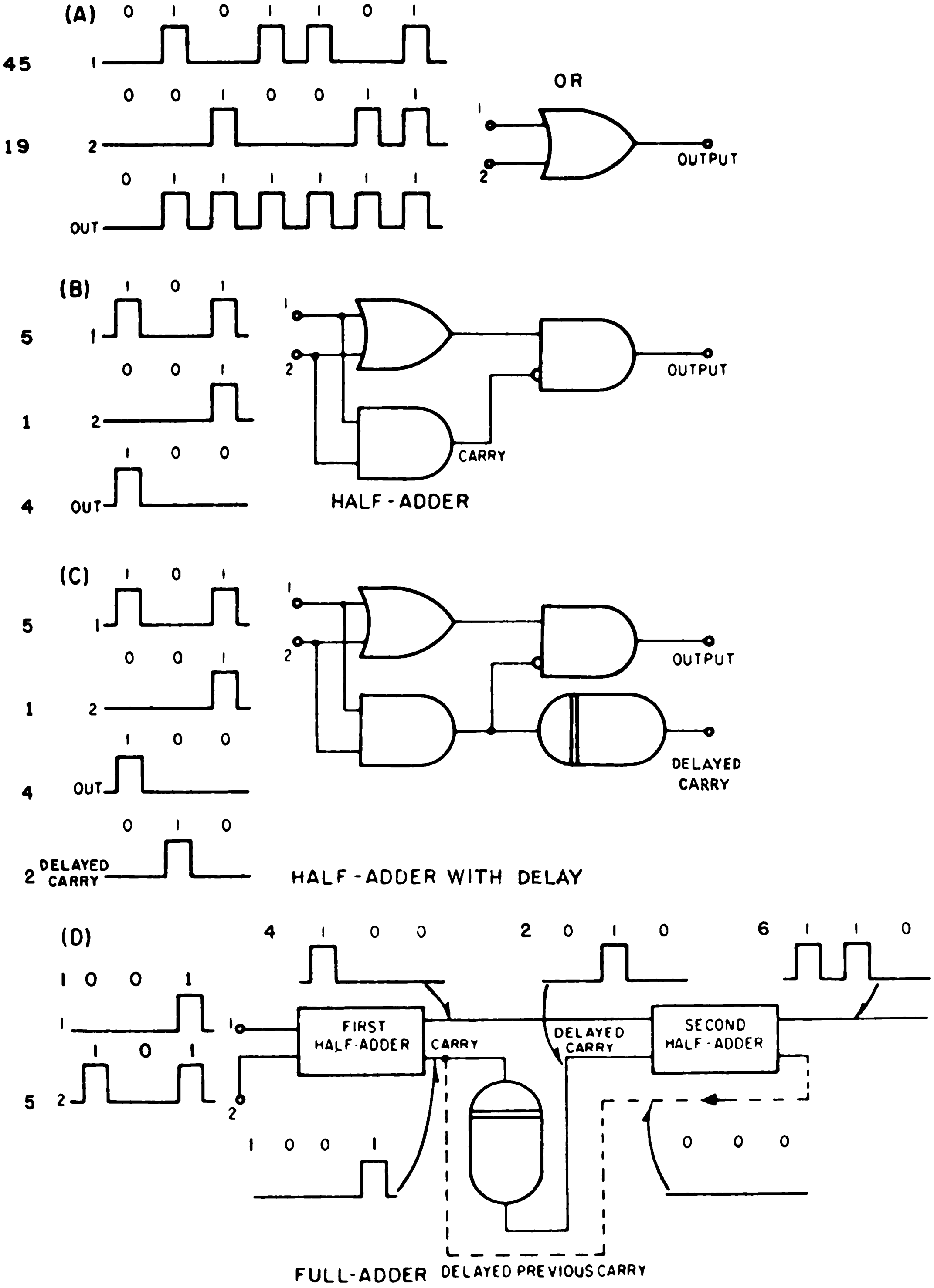

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Figure 7-19.—Binary addition circuits, block diagrams. A. OR circuit; B. Half adder; C. Half adder with delay; D. Full adder.

the 1 carry produced when adding two 1's together in the first column has been carried to the second column. The second half adder has 100 and 010 as its inputs, and adds them to total 110. This is the true sum of the inputs to the first half adder.

Note in circuit (D) that a dotted line leaves the second half adder and enters the delay line. This is a carry recirculation line. In the illustration of the carry function just described, only one carry was necessary, but any number of carry digits may be developed when adding columns of binary words of varying length. The dotted line shows that the carry number may be recirculated any number of times, each time moving the carry pulse one place to the left.

ADDER-SUBTRACTOR

Subtraction in computers is performed by employing the same circuits that have been discussed; namely adders, inhibitors, and delay lines. They are not connected the same as when used in adders; however, each circuit performs its operation in exactly the manner that has been described. The following discussion is a simplification used for illustration.

Figure 7-20 (A) shows the basic subtractor circuit. Its only purpose is to show the subtraction principle; this circuit must be combined with adders and delay lines (as shown in (C)) in order to function as a subtractor and give tr answers. In (A) the inhibitor produces a true mainder when no "borrow" is necessary. (B) however, the remainder is false becau the basic circuit cannot perform the necessa borrow function.

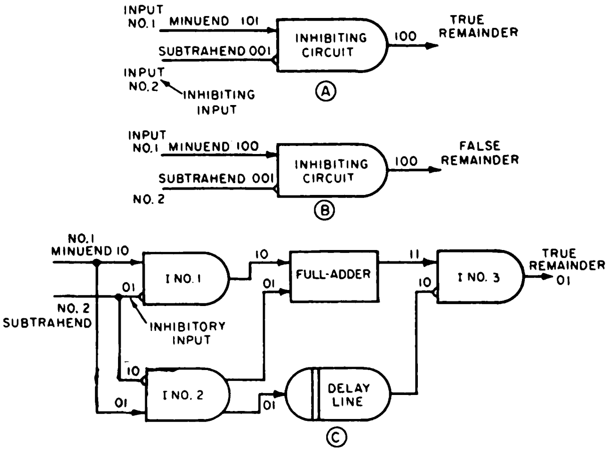

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Figure 7-20.—Binary subtraction circuits, block diagram. A. Basic-No borrow needed; B. Basic borrow needed but not provided; C. Subtractor that borrows.

The subtracting circuit in figure 7-20 (C shows the arrangement necessary to perfo a borrow function. In the following explana it is necessary to refer to the inhibitors by nu ber.

In this circuit it is desired to subtract 0 from 10. At I No. 1 (inhibitor No. 1) the i hibiting pulse in the subtrahend arrives w there is no pulse in the minuend to inhibit the 10 passes through the inhibitor to the add I No. 2 has the same inputs applied, except t they are reversed so that the minuend (becomes the inhibiting input. Here again, t inhibiting pulse arrives when there is no inp pulse to inhibit, so the 01 input at I No. 2 i passed through and appears at two places—t delay line and the adder. At the adder, the tw inputs are added to produce 11 at the input I No. 3. I No. 3 also has an inhibitor puls applied from the delay line which has bee shifted one place to the left to become 10. Thi time the inhibiting pulse at I No. 3 inhibits th second pulse of the input to produce 01 the output of I No. 3. This is a true remainde By shifting the output of I No. 2 one place to th left, a borrow funtion is effectively performe

The circuit just described can perform o one borrow function. For subtraction involvin multiple functions of borrow, additional adder and delay circuits must be incorporated, o the more practical shift register may be use to shift the necessary pulses as required.

MEMORY DEVICES

The kind of storage employed by an automati digital computer is decisive in determining th form a computer may take. A computer's stor age or memory is sometimes referred to simpl as a store.

A computer's arithmetic section is fast. It calculating speed is measured in nanosecond (billionths of a second), thus indicating it mus be fed data at a fast clip. For the computer t quickly find data to work on, it is stored in memor and assigned a specific address. Knowing wher the data is, the computer can find and take it ou in microseconds. In this section we will discus ome of the magnetic devices used to store and to old data and instructions.

EVELS OF STORAGE

Internal storage refers to storage which the rogrammer, or coder, would normally use. It is ocated within the arithmetic unit or main storage, and is characterized by high speed and ow capacity.

Secondary storage is cheaper and slower in access, but it has larger capacity. Access time ould be as small as milliseconds for magnetic drums or up to minutes for magnetic tapes. Blocks of secondary storage are normally transferred to the arithmetic unit as required, instead of addressing a specific storage location of a specific stored word.

External storage refers to punched cards, punched tapes and magnetic tapes stored in files or cabinets, which the computer does not have direct access to. Externally stored information is in a form which the computer can use, but it is physically separate from it.

The capacity of a store is measured by the amount of information in bits or (binary) decisions it can store. The storage capacity of a flip-flop is one bit. A register can store one word at a time, but an array or matrix of magnetic cores may store 10,000 words with fairly small bulk (each core may have an outside diameter of only 50 mils). The storage capacity of magnetic tapes used for external (slow access) storage may be essentially without limit.

Access time is the time it takes a computer to locate data or an instruction word in its storage section and transfer it to its arithmetic unit where the required computations are performed. The time it takes to transfer information which has been operated on from the arithmetic unit to the location in storage where the information is to be stored. Synonymous with read time. Random access is said to occur if access to any storage location is independent of the storage address of the previous word. Access is said to be cyclic if the access time depends on the location of the previous word, as in the case of a rotating magnetic drum. (With a rotating magnetic drum, the addresses available at any given instant depend on the instantaneous drum position.)

Random access time for internal storage may be typically a few microseconds, but for secondary storage, milliseconds to minutes will be required.

Static or dynamic storage refers to whether the information changes location or not (when it is not being used). Examples of static storage devices are flip-flops and magnetic cores. Examples of dynamic memory devices are delay lines (with circulating pulse trains) and rotating magnetic drums.

Erasable storage is widely used in computers since it is essential in many instances to be able to store different words at different times at the same storage location. Examples of erasable storage include magnetic drums and magnetic tapes. Examples of nonerasable storage are punched cards and punched tapes.

Volatility relates to the loss or alteration of stored information due to an unintentional power loss. Regeneration or the periodic reinforcement of stored information, which is a common practice in dynamic storage, usually results in a volatile situation. Modern computers generally have ''power down sequences'' to prevent loss of volatile data in case of power failures. Storage capacitors provide power until the data is transferred to the core memory.

Serial (series) access refers to reading or writing one bit at a time. When all bits of a word are transferred in the same cycle, operation is said to be parallel. Only the smaller binary computers are entirely serial in storage access; on the other hand, very few computers use parallel storage systems altogether. Most use a series parallel arrangement. A parallel arrangement provides high speed at the cost of a great amount of additional equipment. On the other hand, a completely serial situation is usually too slow.

Magnetizing the Memory Unit

The process of recording a 0 or a 1 on a magnetic medium involves two opposing problems:

1. To obtain the highest packing density (storage of the maximum number of items in the minimum space).
2. To maintain reliability (ability to recognize and use the stored data).

In order to obtain the highest packing density, considerable distortion must be tolerated. A saturation amplitude signal is normally used to record digital data, and this results in a gross distortion of the input signal. Figure 7-21(A) illustrates the type of distortion involved.

Signals are produced when the recording material is moved by a pickoff winding in such a manner that cutting of magnetic lines of force takes place. This occurs at the beginning and the end of the magnetized portion of the recording material. No signals are produced by the saturated portion of the recording material because the magnetic lines of force are aligned with the direction of movement. The magnetic airgap (shim) dimensions determine the amount of material needed to record a single data bit.

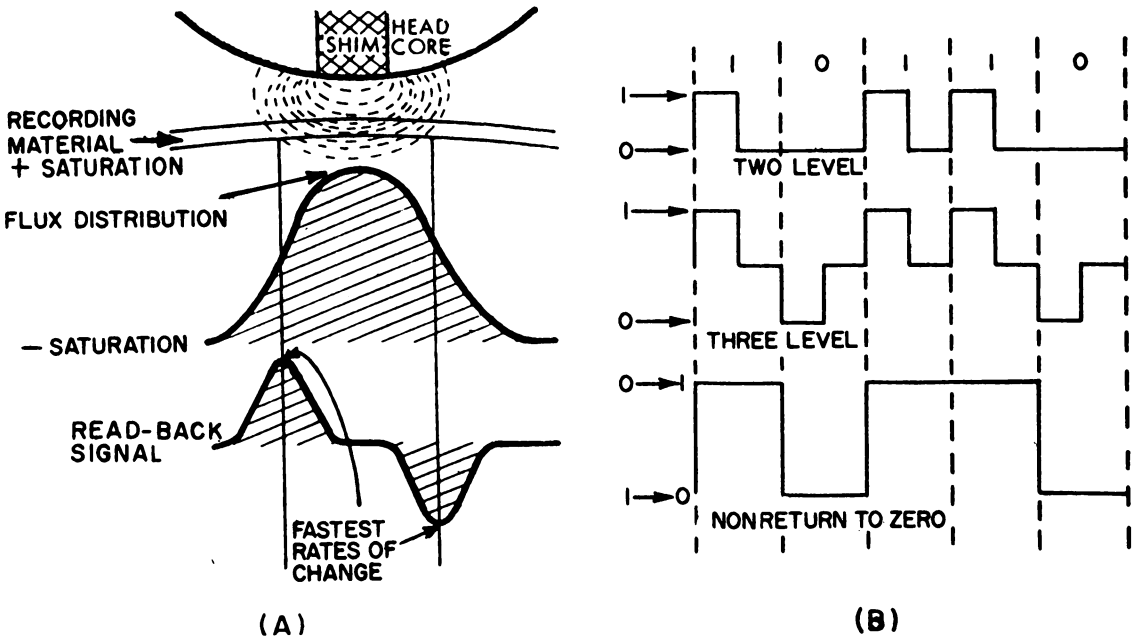
SIGNAL AMPLITUDE.—The amplitude of signals recorded may be two-level or three-level, depending on whether a condition of zero magnetization is allowed to exist other than momentarily. Figure 7-21 (B) is an idealized representation of the binary number 10110 (decimal 22). The top waveshape represents the two-level signal, and the center waveshape represents the three-level signal. In the three-level system, note that zero magnetization exists during the latter half of each data bit, and that the polarity of the magnetization is reversed fo the 0 or the 1 digits.

In a third system of recording (shown in th bottom waveform of figure 7-21(B), no chang of output is permitted when succeeding digit are the same; therefore, no playback signal appears at this time. This is called the NON RETURN-TO-ZERO method of recording. Wit a long series of 1's, counting the time interval is made by clock timing pulses. A separate recording track is usually devoted exclusively to recording these synchronizing signals.

READOUT.—Since the readout signal waveform differs greatly from the read-in signal, additional circuitry is frequently used to restore the signal to its original shape. This circuitry normally consists of a saturation amplifier and clippers.

MAGNETIC DRUMS

Since the computer has a magnetic memory unit that moves under heads, the information stored in the various channels can be changed as an operation progresses. That is, during the time that a problem is being solved—such



(A)

(B)

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Figure 7-21.—Magnetic recording. A. Recording method, showing distortion; B. Recording levels.

s weapon firing time—some of the items of ata will be varying and must be changed as he problem progresses. The heads of pertient channels will be used to erase and rewrite formation in those channels as required.

The magnetic drum is an aluminum cylinder oated with a magnetic material. Heads for riting on or reading from the drum are mounted o that the drum rotates past and close to them. (See fig. 7-22 (A).) The heads magnetize spots along the drum surface when data is fed into the computer, and pick off data as magnetized spots cause a pulse to appear at their outputs. This action is quite similar to that of a tape or wire recorder, except that the portion of the revolving drum that passes under each head can be thought of as a ring or band of magnetic tape.

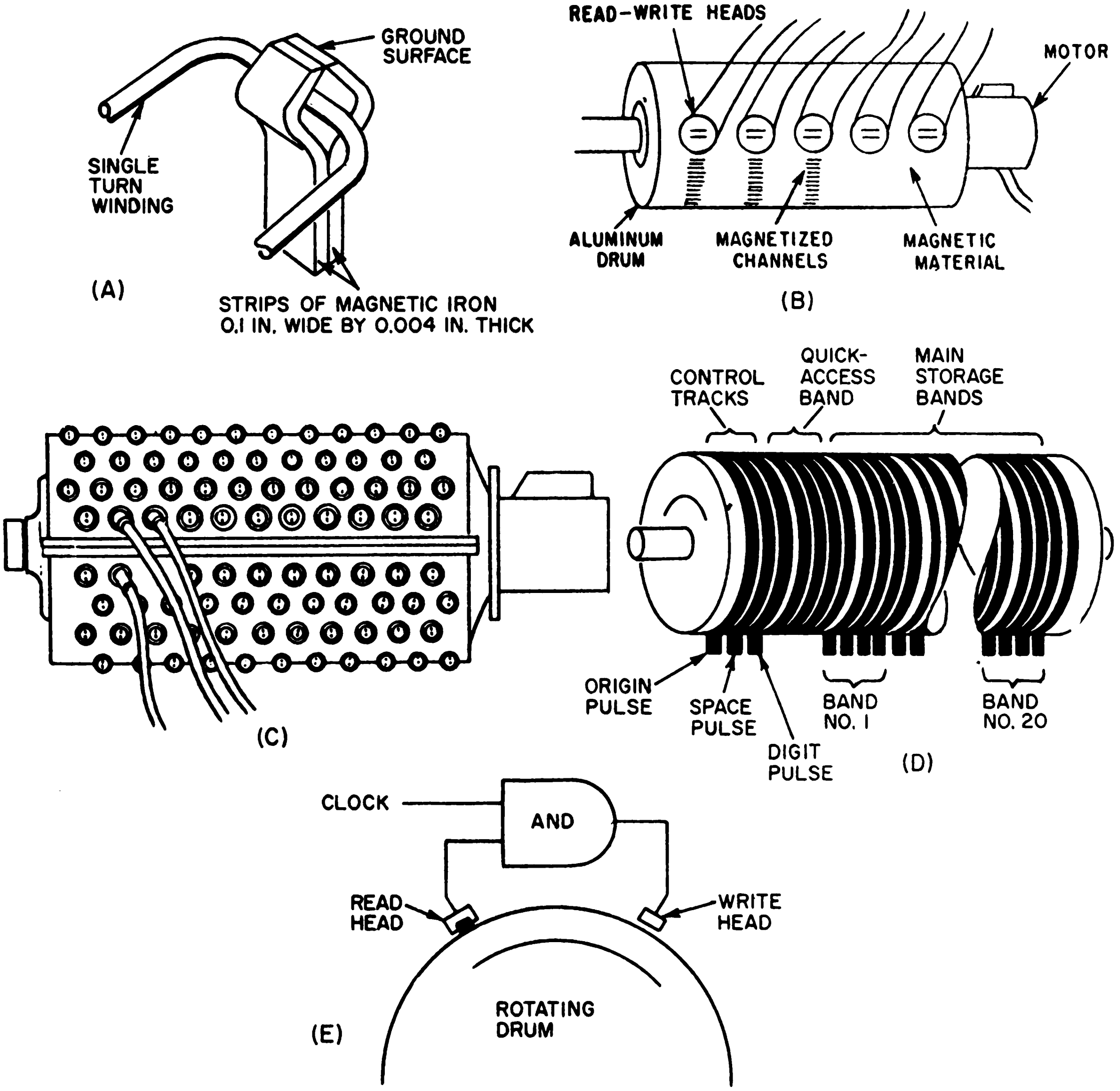

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Figure 7-22.—The magnetic memory drum unit. A. Read-write head; B. Magnetic drum; C. Arrangement of heads on drum; D. Arrangement on tracks on drum; E. Read-write circuit, block diagram.

Figure 7-22 (B) shows how channels appear on the magnetic drum. To place the maximum number of heads over the drum, the heads are staggered as indicated in (C). Each pickup head can be considered as a channel of the rotating drum. Each channel can store approximately 80 bits per inch.

Magnetic memory drums vary greatly in capacity and operating speed. Speeds of 3,000 to 17,000 rpm and diameters of 4 to 12 inches are quite common. Access to data stored on the drum depends on the rotational speed and the location of the particular data desired. When the desired bit has just passed the head, the access time is maximum (one revolution). If the desired bit is under the head, access time is nearly zero. Thus for the general case, average access time is one-half revolution. By improved programming methods, this access time may be further reduced. Average access times in practical computers range from 2 to 10 milliseconds.

The drum shown in (D) includes a quick access band, each track of which comprises several circulating loops of the type shown in (E). These loops waste that portion of track (if any) which is not between the two heads which comprise a loop.

Each channel on the drum is identified, and the location (address) of each bit or word is identified. The channel may be thought of as resembling a motion picture film, with block separations to locate a specific word or bit. The address of a specific binary word is identified as to its channel, block, and location within the block. The blocks will, of course, be very small, as compared with the film.

Many bits are recorded in each block of each channel, and since the bits pass under the head one at a time, some method of identifying the start of a word must be provided. The first channels of the drum have magnetized sectors that provide for positive location of a word or digit within a word. These sectors usually contain pulses used for timing, location of words or word groups, word separation, and bits within a word. The timing pulses synchronize the actions of the other channels. In this manner all the data on all channels is in synchronism with the timing pulse; and if the drum speed varies, every calculation or other operation of the computer varies accordingly. When this feature is incorporated, drum rotational speed is not excessively critical.

The programmer determines exactly what operations the computer is to perform and the sequence of those operations. He then prepares a program for the computer to follow. Information (data) and instructions (the program) are then placed in the computer so as to provide i with the necessary information and the instructions required to control the flow of information The magnetic drum in computers is normally programmed for one specific problem, and is CLEARED of data after the problem is finished and before the next problem is begun. Each new problem requires that new data be programmed into the drum. Programming is discussed later in this chapter.

Ferrite Core Memory Element

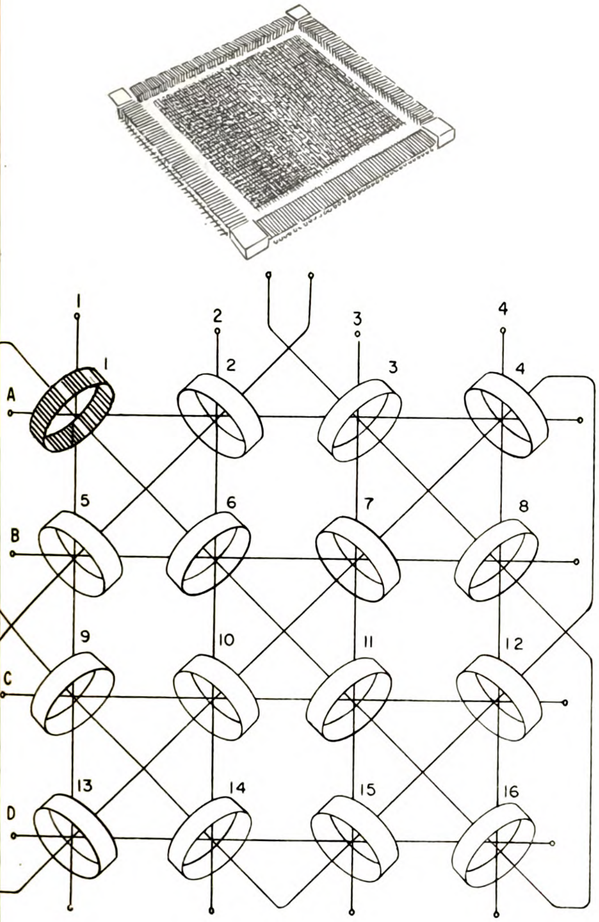
Another type of memory device is the ferrite core. Its principle of operation is similar to that of magnetic amplifiers, in that it is magnetized with a polarity corresponding to the direction of the magnetizing force. The magnetizing force required is modest; a single conductor passing through the core performs the function of a winding.

A magnetizing force applied in one direction magnetizes the ferrite core with a polarity that represents a binary 1, and when applied in the opposite direction causes the opposite polarity which represents a binary 0.

The ferrite core is a small ring of magnetic material, with diameters of approximately 0.05 inch. Figure 7-23 is an enlarged drawing of a section of a ferrite core matrix. A MATRIX is made up of many ferrite cores connected as shown in the figure, and arranged in a flat panel inside a frame, with wires leading out for easy attachment. Very short access times (10 microseconds or less) are common, because modern high speed semiconductor switches make parallel access practical.

The arithmetic and memory units of a general purpose computer contain many of these matrices. Each core is capable of storing only one bit, so a matrix of 250 cores can store only 250 bits. Multiplying the number of matrices by the number of cores per matrix gives the number of bits that a computer can handle.

In the figure, each core has three windings. The wires that cross at right angles are used to magnetize the core. Using coincident current techniques, any single core may be selectively read in or out. By passing a current through both the horizontal wire and the vertical wire which pass through a given core, the two fluxes may be made to add and to just exceed the threshold value necessary for switching



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igure 7-23.—Ferrite core memory section.

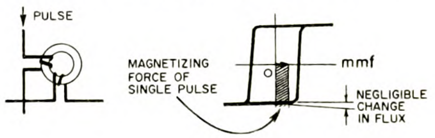
nagnetic polarity of the selected core. Each orizontal wire and each vertical wire passes hrough an entire string of cores. The only ore affected, however, is the core at the intersection of the two wires that have the pulses pplied. As an example, locate the junction f line B and line 2 on the diagram in figure -23. If both line B and line 2 have pulses pplied, only core 6 will be affected, because he magnetizing effect of only one wire is not ufficient to cause the magnetization of the ther cores to flip to the opposite polarity.

The use of a third (sense) winding (S) pernits the sensing of the switching of the core. f interrogated by coincident pulses, the core vill switch and the change of flux will induce pulse into the sense winding. The polarity of this induced pulse is an indication of the binary 1 or 0 that was stored in that core before switching occurred. When the core is read out, the binary bit in that core is lost. This is called destructive read-out because the stored data is lost during the read-out process. If it is desired to retain that bit, it is necessary to recirculate and reapply that bit to the core from which it was read out.

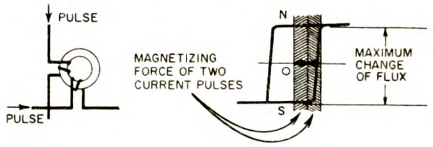
Single pulses will frequently be passed through a core when reading into or out of adjacent cores, but these cause no harm. In figure 7-24 the effect of single and coincident pulses is shown. In (A), a single pulse is shown to produce a negligible change in flux; in (B), coincident pulses are shown to produce a change in flux sufficient to switch magnetic polarity of the core. Residual flux is indicated by the saturation levels, N in one direction and S in the other.

TESTING.—A testing waveform of current may be used to determine the effect of repeated single pulses on a given core. In the ideal situation, a single pulse will have no effect,

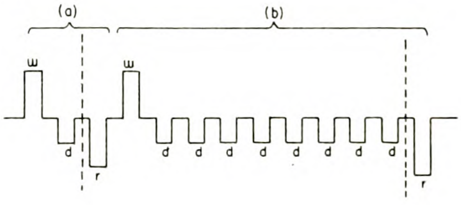
(A) A SINGLE PULSE CANNOT SWITCH THE CORE



(B) COINCIDENT PULSES ON BOTH WINDINGS SWITCH THE CORE



(C) TESTING WAVEFORM



167.120

Figure 7-24.—Switching core polarity. A. Single pulse; B. Coincident pulses; C. Testing waveform.

but this is not necessarily true in practice. To determine the effect of many single pulses on a given core, the waveform shown in figure 7-24 (C) is applied to to the core to be tested. A pickup winding is used to sense the response of the core to the testing waveform, and the output of the pickup winding is applied to an oscilloscope which is synchronized with the testing waveform.

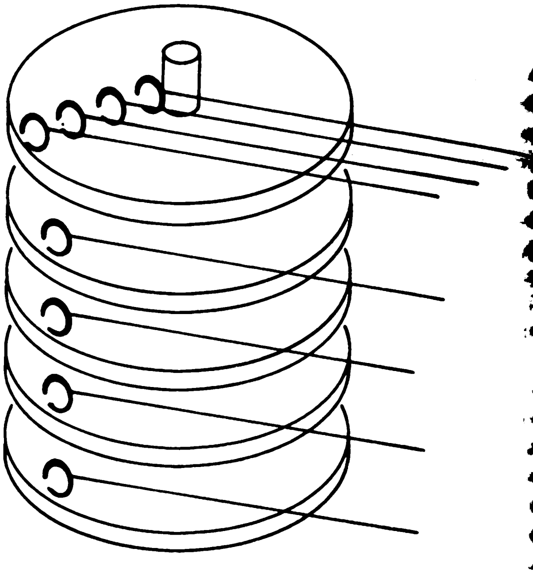
The waveform is essentially divided into two parts. Part (a) consists of a write pulse (w), followed by a single disturbing pulse (d) and a read pulse (r). Part (b) is similar, but includes a series of disturbing pulses instead of a single one. The response of the two reading pulses is an indication of the demagnetization of the core caused by several disturbing pulses (b) as compared with the single pulse in (a). If the response to the disturbing pulses is excessive, the core must be rejected.

MAGNETIC DISK

The rotating magnetic disk used with some computers is increasing in popularity. Its function is the same as that of the drum, but the surface is flat like a phonograph record instead of cylindrical, and the tracks are circular instead of spiral as in a phonograph record. Spacing of the recording heads is maintained constant. Very high storage capacity is characteristic of this device, and the low mechanical inertia makes it appealing. Disk storage units have been built with 100 concentric tracks on each side of each disk. Figure 7-25 shows the construction of the disk type magnetic storage unit.

MAGNETIC TAPE

Perhaps the most "familiar" type of storage is magnetic tape. The materials used for recording may be the same as those used for audio recording, except that a very high quality tape is required to avoid missing an occasional bit. Seven-channel tape (common in computer work) is usually one-half inch wide, and has a recording density of 100 to over 500 bits per inch. A 2,400-foot roll can store about 3 to 16 million characters. (This is less than the apparent maximum, because the gap between recorded sections of tape may be from 1/2 to 2 1/2 inches.) Obviously, the tape must be brought up to operating speed before reading or writing is begun. Actual tape speed may be as high as 240 inches per second.



167.1

Figure 7-25.—Magnetic disk storage devic

Since input and output devices are general mechanical, it may be advantageous (both f speed and economy) to record the computer ou put at its optimum speed on tape, and later pl it back at any convenient speed into the appro priate terminal unit. Similarly, a separate ta track may carry other data essential to t evaluation of the tape.

Tapes produced by computers are used e tensively for controlling other processes. Sinc the data is digital, it can be operated at variou speeds, and even stopped, with no loss or dis tortion of data while other operations are per formed.

Many techniques are available to overcom random data acquistion on tapes. These includ use of multiple tracks, multiple read heads etc. The chief advantage of magnetic tape its ability to store millions of data bits in expensively. Under ordinary operating condition magnetic tape is usable up to 50,000 times. Dat on a used tape may be transferred to a new on Temperature and humidity must be controlle as variations may cause the oxide surfaces crack. Since dust may cause a signal to missed, extreme care in manual handling necessary. Oil or moisture from manual handlin may encourage the collection of dust.

THER MAGNETIC DEVICES

A readout device with characteristics similar those of the ferrite core, but whose stored ta is not destroyed in the reading process, is lled the TRANSFLUXER. Figure 7-26 (A) ows that a second, smaller aperture is used permit sampling and possible switching of ly that portion of flux which exists around the nall hole. During readout, this device does ot switch all the flux contained in the core. he transfluxer may also be used for storing alog quantities.

The THIN FILM DOT ARRAY memory device hown in fig. 7-26 (B)) promises very fast, ompact, and inexpensive switching. Access time f 0.2 microsecond has been demonstrated. The agnetic characteristics of this thin magnetic urface are directional in nature; the film is asy to magnetize in one direction, but hard a direction at right angles to that direction. he magnetization characteristic in the hard direction is essentially without hysteresis (instead of a B-H loop, it collapses into a line), but the B-H characteristic in the easy direction is the familiar square loop.

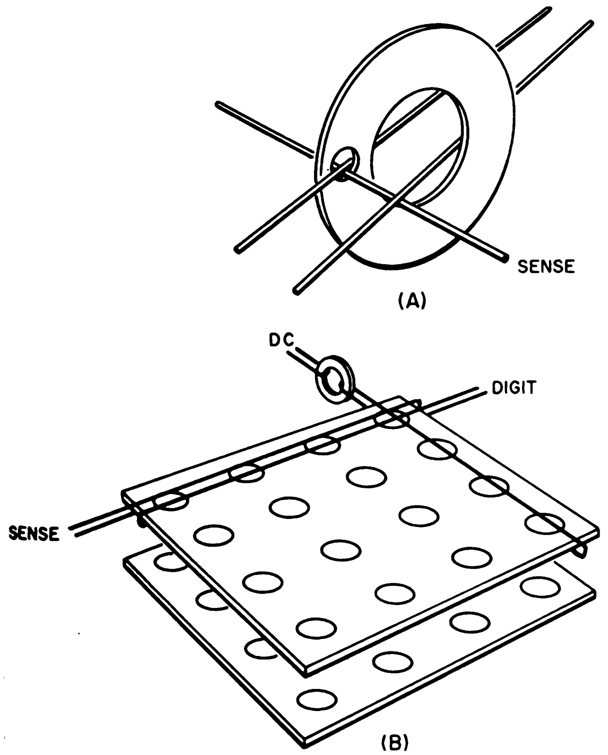


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Figure 7-26.—Other magnetic memory devices; A. Transfluxer; B. Thin film dot array.

PROGRAMMING

A modern digital computer is capable of adding and subtracting almost indefinitely with lightning speed. Some can also make decisions, based on the results of th previous calculations. However, despite these capabilities, the computer cannot automatically perform its functions by itself. Each step of the problem that the computer is to solve must be worked out in advance by a ''programmer.'' The programmer is someone who decides how the problem should be worked by the computer and then writes the program which outlines the sequence of operational steps. These instructions must be placed in the computer, and made to activate the internal circuits so that the computer will process for solutions to problems.

The programmer may not be concerned with the actual answer to the problem but only that an answer is produced and placed in the memory unit at a specified address. The computer may be instructed to perform the same operation over and over; and if any of the data changes, the solution will also change. The solution to one problem is often used in making other calculations required in the overall operation.

The programmer for a computer does not necessarily need to know the mechanical or electronic theory of a computer, but he does need to know its maximum capabilities.

CONTROL

The switching or routing system of signals in computers can be compared to a huge railroad yard where many trains being routed through a maze of tracks. All the trains are controlled from a central point and move as directed by the controller.

A train is formed by directing an engine to move through the maze of tracks in the yard, picking up one or more cars at designated points. The completed train then moves out of the yard as an integral unit. The paths followed in forming the train were predetermined and directed in sequence by the controller. In similarity, the control unit of a computer will be the controlling device that does the switching, and the courses taken by the binary bits will resemble the tracks of the yard. In the output of the computer, the completed data will be analogous to the train.

THE PROGRAM

When the programmer makes a program for a computer, he determines the sequence of operations necessary to solve a problem. Many automatic functions are built into the computer, such as switching, counting, arithmetic operations, and others involving the special mechanics of arithmetic employed by computers. A program may be set up so that each operation is given a coded number designation, and the programmer merely inserts the coded numbers as instructions to the computer. Programming is technically only one part of preparing a problem for solution by a computer. Actually there are four major steps, as shown in figure 7-27. These are numerical analysis, flow charting, coding, and checking. These jobs are frequently referred to collectively as ''programming.''

NUMERICAL ANALYSIS

Numerical analysis is the definition, in proper mathematical terms, of the problem to be solved. It is the science (or the art) of reducing problems into terms, quantities, and equations that a digital computer can accept. In all but the simplest problems, extensive numerical analysis may be required before the program can be written. How does one represent an integral or differential, a cosine, or a quality? Numerical tricks, approximations, and even arbitrary values must be used in order to translate these concepts into the discrete, numerical values required by the computer.

PROGRAM PREPARATION

Normally problems are too long and too complex to encode directly from the mathematical analysis. Programming provides the shorthand, or guide, which makes it possible to translate the mathematical operations into the step by step operations required by the specific computer to be used. Programming is primarily the task of drawing flow charts, or block digrams, and planning memory allocations.

A flow chart (illustrated in (B) of fig. 7-27) is essentially an annotated block diagram and is an organizational convenience. In addition to depicting the overall system logic, it shows the sequence of logic operations, the result of each choice, and the time and entrance point of all new data.

Although it is intended principally as an aid in writting the computer code, the flow chart is also an excellent troubleshooting and testing device. It has symbols to describe the various functions to be performed, to indicate a logical choice or optional sequence, and to show when a sequence is changed by new or modifying instructions. Additional symbols and conventions are generally used to simplify the diagram and to make it a more complete instrument for aiding the man writing the code. These symbols are not standard, but they are usually consistent in a given set of charts. Their main purpose is to transfer information from the designer to the coder or other users of the computer.

CODING

Coding is the step by step transformation of the problem, as mapped out by the flow chart, into a final program written in the language of a particular computer. Coding is essentially a painstakingly precise bookkeeping operation; each address, each digit, and every single command must be correct.

The coder, unlike the man who writes the flow chart, needs little knowledge of mathematics, he does not even need to understand computers. The only absolute requirement is that he adhere inflexibly to the rules as established by the design of the computer. Generally, in transferring from one type or model of computer to another, the coder must learn a new set of rules, a new computer language, or a new code.

CHECKING

Checking, or verifying, is the final step in what might be called the ''training'' of a computer. It is frequently performed automatically. The sole purpose of this step is to insure that the coder has made no errors. The program prepared by the coder may be stored internally or externally. Storage will be semipermanent or permanent depending upon the purpose and application of the computer.

INPUT AND OUTPUT DEVICES

Plug-in devices are used extensively in analog computers to increase versatility and accuracy. The primary application of plug-in units in

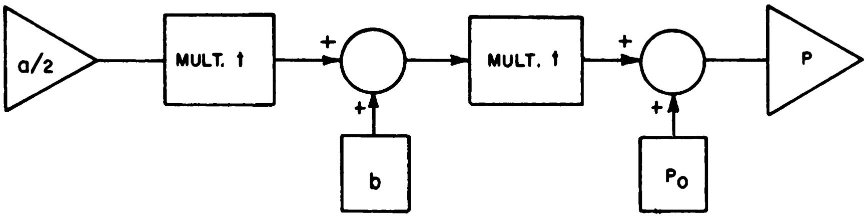
(A) **NUMERICAL ANALYSIS**

PROBLEM: DETERMINATION OF POSITION

$$P = at^2/2 + bt + P_0$$

a = ACCELERATION
b = VELOCITY
P_0 = POSITION AT $t = 0$
t = TIME

(B) **FLOW CHARTING**



(C) **CODING**

INST. NO.	INSTRUCTION
1	READ IN $a/2$
2	MULTIPLY BY t
3	ADD b
4	MULTIPLY BY t
5	ADD P_0
6	READ OUT

(D) **CHECKING**

INST. NO.	
1	$a/2$
2	$at/2$
3	$at/2 + b$
4	$at^2/2 + bt$
5	$at^2/2 + bt + P_0$

$$P = at^2/2 + bt + P_0$$

Figure 7-27.—A simple program for a digital computer.

167.127

large digital computers is to supply multiple input and output devices capable of being individually and/or collectively coupled to the computer. Numerous devices have been developed to take advantage of the speed of the computer; a few of these devices are described below.

CONVERTERS

All converters are essentially counting, weighing, or reading devices. The output of the converter should be compatible in form and time availability with the computer that is to use it. The speed, precision, and accuracy required of the measurement determine the type converter used. Since the majority of inputs to Navy computers are available in analog form, the analog to digital converter type input is used extensively. Devices of this type are available to convert most analog inputs to digital form with almost any desired degree of accuracy.

In the sample program just discussed, the values of a, b, and P are variable (and possibly constantly varying) quantities which are available in analog form from instruments or from computer sections. The following paragraphs discuss briefly each of the quantities, fixed or variable included, in the problem.

1. Acceleration (a) is available from a tracking system accelerometer in some form such that the output of the device is proportional to (analogous to) the acceleration. It represents a change in velocity.

2. Velocity (b) is variable during the problem time and this quantity may be available directly from the computer, or it may be stored in an easily erasable memory circuit and corrected as the occasion demands.

3. The time interval (t) is determined by clock timing pulses. The shorter the time interval (and the more nearly constant the clock PRF), the more accurate the possible computtations.

4. Position at time zero (P) indicates the target's position at the beginning of the time interval. At the beginning of the solution, this position may be inserted manually, or it may be made available to the computer from an automatic tracking system.

5. Present position (P) represents the solution to the problem, and is the usuable output of the computer. Since this data is continually being revised each time the computer cycles through the program, it is stored in an easily erasable address.

If it were necessary to determine each these quantities, to convert them into digital form encode them and determine the program, and appl these to the computer, the computer spe would be of no significant value in one-ti solutions. The value of computers in act tactical situations lies in the automatic and rep titive nature of the computer. Specifically, th includes the following abilities:

1. To accept the required data automaticall provided only that it be included in the progra and that it be in the proper form for use b the computer.

2. To perform the programmed computation with great speed.

3. To perform the same computations ov and over again.

4. To make corrections during each compu tation cycle, as the situation requires, reflecti any change in values that may have occurre since the last previous cycle.

5. To store the result of the last previo calculation for use in the next computatio

In the problem under current consideratio refer to figure 7-27. The program is buil into the computer, all required data is immedi ately available from instruments or other com puters, or it is stored in the storage unit o the computer. In connection with the soluti of this particular problem, certain pertinen factors must be considered.

If the target is moving at a constant velocit the acceleration is zero, and the prelimina solution to "at/2 + b" is simply "b". The val of b from the previous cycle of computation i stored at a specified address in the memor unit and is recalled and used in the solutio

If the target changes velocity, some rate-of change sensing device is used to sense a evaluate the acceleration taking place. Any i crease in velocity represents a positive a celeration, whereas a decrease indicates negati acceleration. The computer must be capab of distinguishing between the two, and must b able to make the computation for either.

Multiplying the average value of accelerati (a/2) by time (t) during the time interval (at/ determines the change in velocity which h occurred since the previous computation cycl Adding this correction to the former value o results in a new velocity, which is used in th esent cycle and then stored in the memory unit the "b" address for use in the next solution. Multiplication of the new value of b by the ne interval determines the change of position t has occurred since the last cycle, and icates the correction that must be added to last known position (P) in order to deter-ine the new P.

P_0 represents the last known position, and stored information. Adding the correction to last previous result provides the computer h a new value of P which is the usable output the computer. This information then be-mes the P_0 for the next computation cycle.

If it is desired that a computer should con-ually calculate the course and distance from present position to the point of origin, another ction of the computer could be programmed perform the computations involved. This would quire a permanently stored reference position, d additional circuitry to compare the two po-tions and to compute the course and distance tween them. Readout of this information could made continuous, or it could be made avail-le upon demand. If the solution is required ly upon demand, no storage is needed; if is to be continually computed, storage should in an easily erasable form, since it is ntinuously changing.

PUT DEVICES

An input device is considered to be any de-ce which yields an output which is usable for particular computer it feeds. The devices ich will be discussed are referred to as con-rters or encoders because they convert analog formation into digital information.

alog to Digital Converters

The variable quantities just mentioned could iginate in analog devices. Since a digital com-ter accepts only binary quantities, the analog ta must be routed through a converter and nged into digital form for insertion into computer.

Analog elements determine the present values each quantity and supply them to the converter, ich then converts the data into digital form. computer may have a program outlined by ich all the variables are considered in cal-lations that finally result in a YES or NO swer. The YES answer might cause a green dicator to light, and NO might cause a red indication. The computer may cycle the program continually, correcting the various quantities as needed, and temporarily storing the rate of change of each quantity, as well as the value of the latest computed quantity. With this arrangement, computations based on latest available data can continue in the event of interruption of operation, and the margin of error is decreased in that event.

The limit of accuracy of a computer is the least significant digit. There is no advantage in having an analog device more accurate than the control data available to it. As an example, a servo positioned by a five-digit binary control signal can indicate no closer than 1/32 ($2^5 = 32$) of a revolution, or approximately 11.3°, regardless of the precision of the servomotor itself. The precision of output devices should be matched to the stored data, or at least to the level of accuracy required in the output application.

Electrical Converters

The analog input to an analog-digital (AD) converter which uses the electrical technique for encoding must first be converted to a voltage. This conversion is achieved by using some type of transducer (a device which converts energy from one form to another, as from mechanical energy to electrical energy). Some common types of transducers are microphones, loudspeakers, phonograph pickup heads, and synchro systems which use a transmitter as the input device and a transformer as the output device.

In many computer applications it is necessary to transform an analog input voltage into a form more suitable for decoding. We will briefly discuss an analog to digital converter used in a typical Signal Data Converter (SDC). The analog-to-digital converter will accept analog input signals. The signal converters that make up this section include synchro-to-digital, AC-to-digital, and DC-to-digital. All analog input signals and references are applied to high impedance line receivers that perform dual functions: (1) they isolate the SDC conversion components from the signal sorce, and (2) they convert input signal amplitude to SDC usable levels. In the absence of a Start Sequence command, synchro and AC input data are sampled periodically, and the sampled signals are held (stored) in capacitors. DC input signals are applied to a low-pass filter and the filter output is sampled. When a Start Sequence command is decoded, further sampling is inhibited for the sequence duration. Stored signals are multiplexed into the appropriate analog-to-digital converter.

Synchro input signals are conditioned by the SDC to sine and cosine components of synchro shaft rotation. Three-wire synchro input signals are applied to solid state Scott-Tee devices. Within the device, a simultaneous voltage step-down and conversion to sine and cosine values of the transmitted quantity is accomplished. Scalar AC and DC inputs consist of signal and reference. When the conversion is complete, each resultant digital signal is stored in the appropriate converter register. Input sequence control signals then determine when the Digital Multiplexer will select the proper converter register contents for input to the Input Buffer Register. From the Input Buffer Register, the digital word is transferred to the computer via the Input Level Converter. The function of the Input Level Converter is to change the binary 0 and 1 voltage levels from SDC scaling to computer scaling.

VOLTAGE TO NUMBER CONVERSION.—Electrical analogies (analos) of most measurable quantities have been developed, with most instrumentation presenting its output as a scaled voltage (1 volt = 100 miles, 1 volt = 1,500 gallons, etc.). It is necessary to convert both the voltage level and the scale factor into terms usable by the computer. It is not always necessary that the scale factor be inserted, as long as the computer has it stored at a unique address.

VOLTAGE-TO-TIME-TO-NUMBER CONVERSION.—A converter of the voltage-to-time-to number type, in its simples form is very useful in scaled systems. The converter may require clock pulses, a linear sawtooth of voltage (ramp), a voltage comparison circuit, and a voltage that is to be measured.

Digital conversion is provided by starting a digital counter that has been synchronized with the sweep, and stopping it when the sweep voltage and the unknown voltage are equal. The clock pulses are counted, and the voltage change per unit time factor is applied, so that the output reading is converted into a number. There is one counted output for each sweep so long as the unknown voltage is within the calibrated range of the sawtooth.

Accuracy of this system is limited by the slope of the sawtooth, by the accuracy of the timing system, and by the precision of the voltage equality determining system. Making the same measurement concurrently (using two or more converters) and averaging the results decrease the inaccuracies of the system.

The system indicates an instantaneous val nothing is shown concerning the behavior of t input voltage before or after its intersectio with the sawtooth.

The sawtooth need not be linear, provid its voltage as a function of time is known a used in the calculation.

SELECTIVELY ADD-SUBTRACT SYSTEM. The operating principle of this system is same as that of the equal arm balance, wh an unknown weight in one pan is balanced selectively adding or subtracting known weig in the other pan. The limit of accuracy, disre garding friction, is ± 1/2 the smallest balanc weight available. Similarly, a voltage balanc analog system, selectively adding or subtract ing scaled resistors until balance is obtained may be used. The advantage of this system i that the voltage may be larger or smaller tha the reference voltage. A simple example is balanced bridge with binary adjustments. Th system may start from a fixed point or fro the last used point, with switching automaticall sequenced and controlled by the computer.

OUTPUT DEVICES

Input and output devices are similar in op eration but perform opposite functions. It i through the use of these devices that the com puter is able to communicate.

Output information is also made available i three types: human information, such as code or symbols presented on a cathode-ray scree which are used by the operator to answer questio or make decisions; information which operate a control device such as a lever, aileron, o actuator; or information which is stored in machine language or human language, on tapes printed media.

Digital to Analog Converters

It is often necessary for the digital output t be converted to analog quantities in order t actuate a servo or some other device of a analog nature. Again, a converter is required but in this case, it must be a digital to analo (D A) converter.

Practically any encoder (analog to digital con verter) can be used as a decoder (digital t analog converter), either directly or in combina tion with a null-seeking driver. Frequently th only modification required is reversing the inpu and output functions of the device.

adout Devices and Methods

Symbolic displays are generally employed r immediate use. The display system (matrix) ay be formed by an array of individual lights; may be variations of intensity or color on CRT; or it may be the locus of points on an Y plotter or on a DRT plotter table. Computer tput voltage levels and data rates can be apted to produce any of these displays. The cific type selected will depend primarily on application.

Timing and retentivity (or recording) may be lected to provide a display similar to that of an oscilloscope, of a radar indicator, or of a television set. The data can be arranged in alphanumeric, graphic, or photographic form. Multiple displays, using combinations of several individual display systems, are used in most airborne and military computers, both digital and analog. Figure 7-28 illustrates several common readout devices.

LIGHTS.— Each individual light may be considered as the equivalent of a binary stage: ON — true or one; OFF — false or zero. Lights are used to display such discrete data as fail-safe, on-off, and warning. They may be used

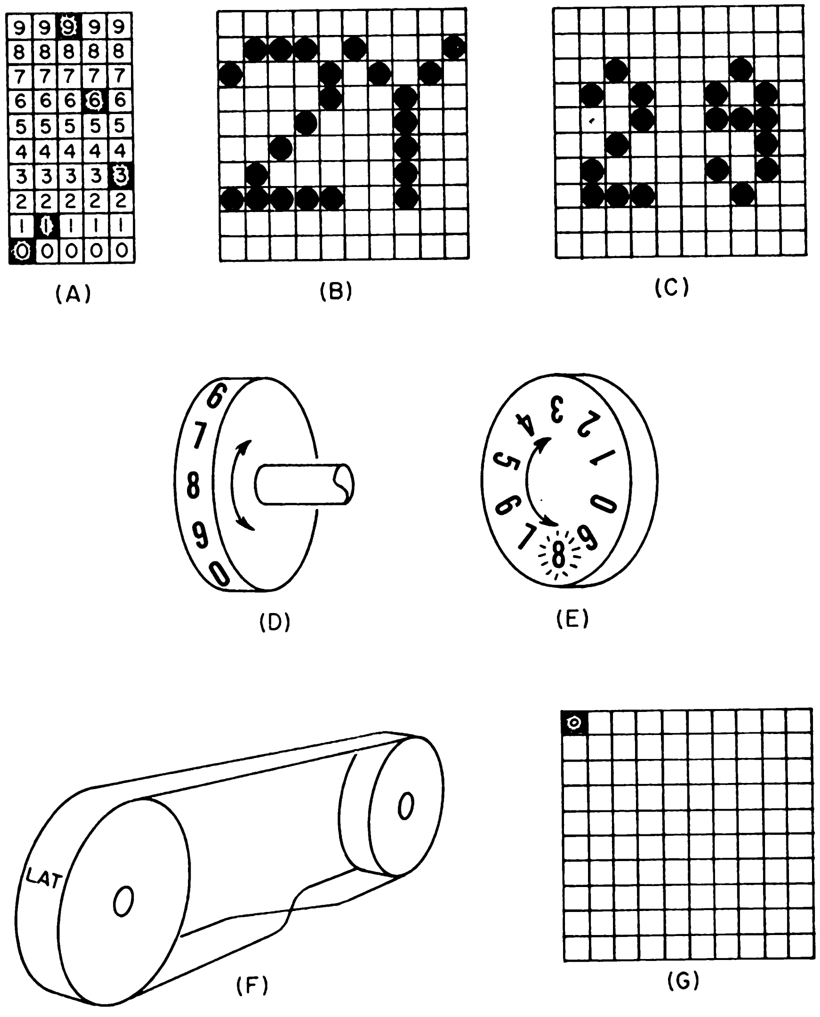


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Figure 7-28.— Readout displays.

in groups and in conjunction with ring counters to form binary to decimal displays. Each individual light is sequenced and illuminates the appropriate digit when switched on by the counters. (See fig. 7-28 (A).)

MULTIFILAMENT LIGHTS.—These lights may display numbers, letters, symbols, or combinations of these. Filaments may "edge light" lucite cards to illuminate engraved symbols, or may actually be shaped in the form of the symbol and glow when switched on. (Note fig. 7-28 (B) and (C).)

Lights require appreciable current—greater than that which is normally available directly from the computing circuits. Therefore, a buffer or amplifier stage is usually required to furnish the additional current. Since a single display illuminates multiple symbols and requires at least one terminal for each, it may require its own counter circuits to convert from binary code to the display code, or it may share a common converter with several other circuits. On the other hand, the individual filaments may be prewired to a printed circuit board, and the appropriate display selected and switched by computer circuitry.

The value and quantity being measured may be represented by a positioned display of multiple filament lights. The digital voltmeter is a fairly common example of the use of these lights.

POINTERS.—Pointer displays may be either of the angle-indicating or of the angle-seeking type. Any one of the angle to number converters previously described can be connected as an output device, either to furnish an angle signal or display (pointer or servo signal) or to mechanically position a particular symbol on a wheel display. The symbol to be displayed can be any arbitrary number, letter, word, or other symbol selected by the designer.

The wheel can be positioned by a servomotor, by a step counting switch, by a D A converter coupled with a motor, etc. The only limitation on the positioning system is that it must be able to drive the wheel until the correct symbol is displayed.

The display may be generated by wheels geared together in a fixed ratio (as in an odometer) or with each wheel individually driven and positioned. A disadvantage of the second system is the increased frontal area required to accommodate the drive mechanisms. The number of symbols to be displayed is limited by the size of the wheel and by the number discrete positions that can be selected. (S fig. 7-28 (D) and (E).)

TAPE DISPLAYS.—Rather than increasi the size of the wheel to increase positio accuracy and to increase the number of symbo that can be displayed, tape displays are fr quently used (fig. 7-28F). The small whe simply acts as an idler wheel for a tape beari a large group of symbols. This system h several advantages, but the primary advanta is that it provides a clearly legible (precis display in a minimum of space. Many "game can be played with the tape system to increas packing density. The digits of several tape may be alined and projected. The depths of th tapes can be staggered, making it possib to package the drive mechanisms in line wit the tapes. The tape can be coded and ma actually carry the control wiring for its ow positional drive motor, simplifying external wir ing.

PLOTTERS.—Digital computers frequentl use plotters to represent two properties of variable: latitude and longitude, altitude an bearing, amplitude and time, etc. Most digita plotters are simply plotters which already exis for analog systems, with the computer merel furnishing signals through D A converters a the input signals.

The plotter may be either of the recordin or the nonrecording type. The digital data displayed (plotted) are a series of discrete values If the points are redily distinguishable fron each other, more than one curve may be plotte at one time. The plot is affected by the numbe and type of recording heads, the speed of re sponse, and the rate of travel. Since it require no motion, the nonrecording CRT is one of th fastest plotting systems, and is one of the mos commonly used.

Another common system, the moving ribbo recording oscillograph, uses pencil or pen o regular or graph paper, pressure-sensitive paper electrosensitive paper, Xerography, photograph or waxed paper. The motion of the paper gene rates one dimension (generally the time, control, or X coordinate), while the lateral motio of the recording device generates the seco dimension.

In other systems the recording device moved in both the X and the Y coordinates ove a stationary surface. This is the principle the oscilloscope and the DRT table. A direc digital control divides the X-Y plane into discrete points, determined by the matrix. A buffer stage may be necessary between the measured voltage and the converter, in order to insure sufficient power to drive the mechanical device. The buffer may be gated to accept a signal only upon command from the computer, or it may be gated continuously.

Selection of the type plotter for use if frequently made on the basis of the input signal. Slowly varying signals may use a mechanical device, while rapidly varying signals may require a more rapid system. Figure 7-28 (G) illustrates a display of Cartesian coordinates by means of individual lights.

OPERATIONAL CIRCUITS.—Another set of outputs commonly used in military computers is the operational outputs; actual command and control signals to other systems or subsystems. They may be in any of the forms previously discussed.

This operational control capability is one of the most dramatic and most respected properties of digital computers. It makes possible the automatic factory, the automatic system test, and the crewless tanker. The computer can do many things faster than men, and it can do many things better than men. However, it can do neither if it is not properly maintained and properly applied.

ANALOG VS DIGITAL COMPUTERS

Any comparison is complicated by the fact that the two techniques are fundamentally different, even though both may be used to achieve the same end result. Thus, a general comparison of analog and digital computers is not possible. Each factor must be considered in regard to a particular problem.

PRECISION

A most significant difference in analog and digital methods is the different degrees of precision.

The precision of an analog computer can be increased up to a certain point. Beyond this point, the physical size and weight, solution time, failure rate, etc., increase beyond all proportion to an increase in precision. In a digital computer the size and weight, solution time, failure rate, etc., is increased approximately proportional to the amount of the increase in precision. Where solution time is critical, precision exceeding the most demanding weapons system requirements is easily obtained in a digital computer. When solution time is not critical, the precision of a digital computer is unlimited, because the problem can be handled in parts.

SOLUTION TIME

The question of solution time is not as clear-cut as most other criteria of computers. The simplest digital computer capable of solving a given problem will usually require more time for the solution than the simplest analog computer, as is the case for problems encountered in weapon systems. On the other hand, a more complex digital computer is often faster than the analog computer. The comparison of solution time is further complicated because of the fundamental differences in the nature of the output data. The analog computer produces continuous output data. While the interval between the time the first input data is available and the time the first usable output data is available may be large, any changes in the inputs are very quickly reflected in the output data. The digital computer requires the same amount of time to process the first input data as it requires to process all subsequent inputs.

RELIABILITY

The analog computer has proven more reliable than simple digital computers in the past. Conversely, digital computers with extensive self-checking and error-detecting features are usually more reliable than analog computers. The reliability advantage of analog computers over digital computers is decreasing as development of digital devices continues.

CAPABILITIES

The area of capabilities is one in which few conclusions can be drawn. Almost all mathematical problems which can be handled by one type of computer can be handled by the other. The only generalization which can be made is that the analog computer is better suited to handling single problems involving continuous quantitiative computation, while the digital computer is better suited to handling multiplex problems involving logical decisions.

COMPUTER APPLICATIONS

Computers already perform many functions in naval weapons systems, particulary in fire control, and can be expected to perform many more functions in the future. Tracking, prediction, missile control and guidance, and tactical display problems are handled by computers.

Since analog techniques are particularly suited for continuous quantitative calculations, and digital techniques for discrete logical calculations, the use of both types in the same system is practical. As pointed out earlier, however, the necessity for converting data from analog-to-digital and digital-to-analog form is required, as is shown in figure 7-29. The input data for fire control systems are almost always in analog form. Tracking data must also be in analog form to be useful. Therefore, if a digital computer is used, data conversion is necessary whether an analog computer is used or not.

DIGITAL COMPUTER Mk 152

Digital Computer Mk 152 is a general purpose stored-program real-time digital data-processing device used to solve Talos, Terrier, and Tartar fire control problems and to control operation of the weapons system.

FUNCTIONS

Principal functions performed by the computer in a typical shipboard installation are summarized as follows:

- Communications with other elements of the weapons system in time-multiplexing fashion through an interfacing device.

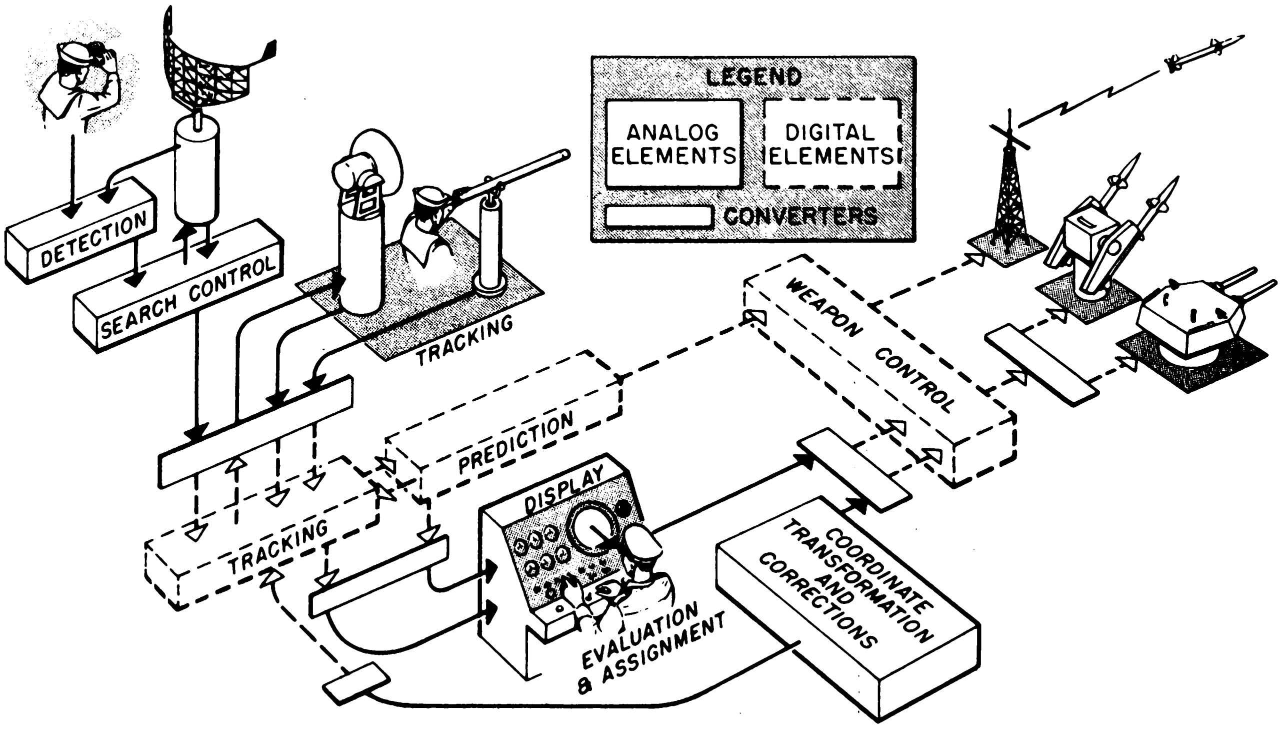

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Figure 7-29.—Complex fire control computing system.

- Operation in conjunction with ancillary or peripheral equipment as, for example, the Input/Output Console Mk 77; acceptance of data loaded through a keyboard or tape reader; and output of data which may be monitored through a perforator and printer.

- Performance of logical, sequential, and arithmetic operations required to solve fire control problems and to control weapons system units.

- Utilization of a priority scheme having decision-making capabilities.

- Performance of self-test functions manually and automatically for itself and for peripheral equipment under the control of the computer test programs.

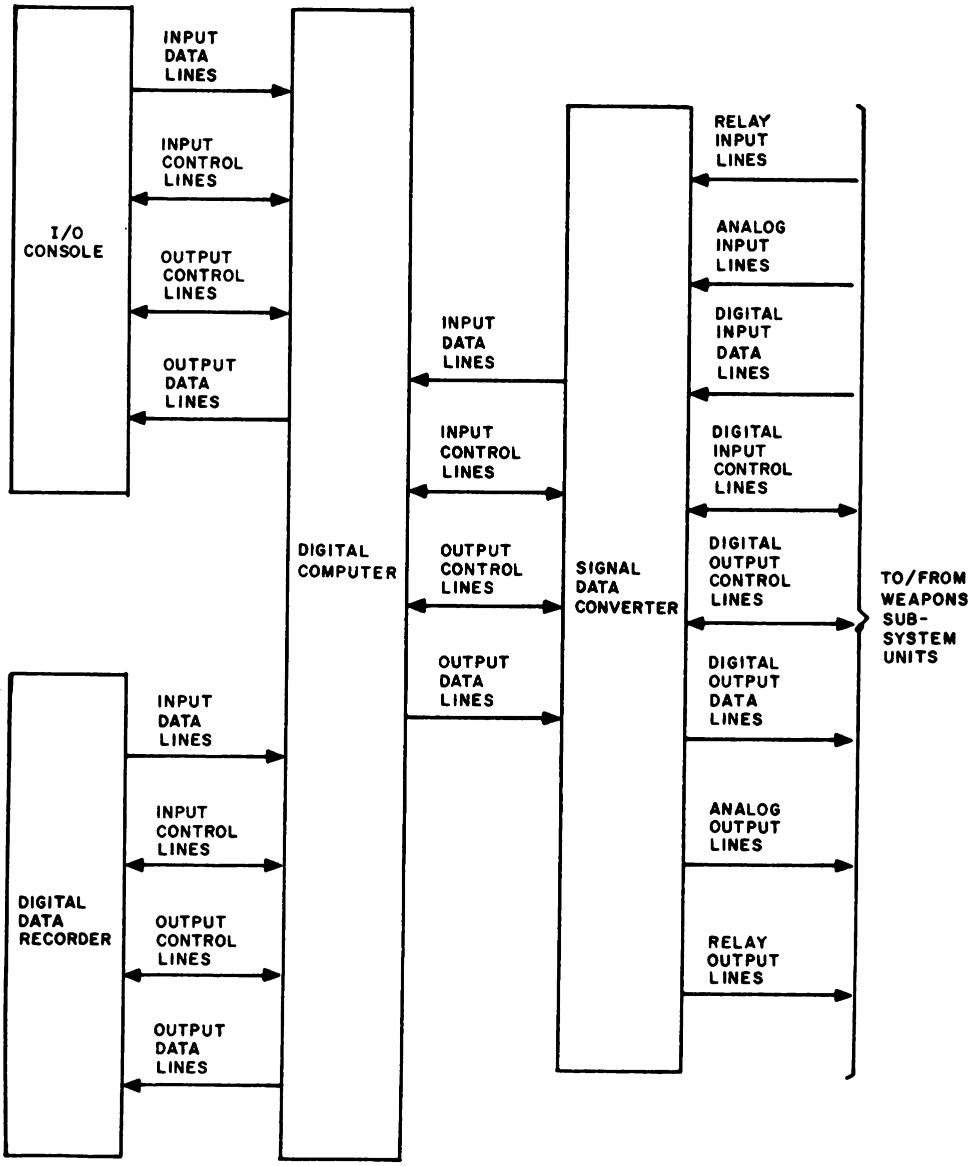

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Figure 7-30.—Block diagram of a typical computer complex.

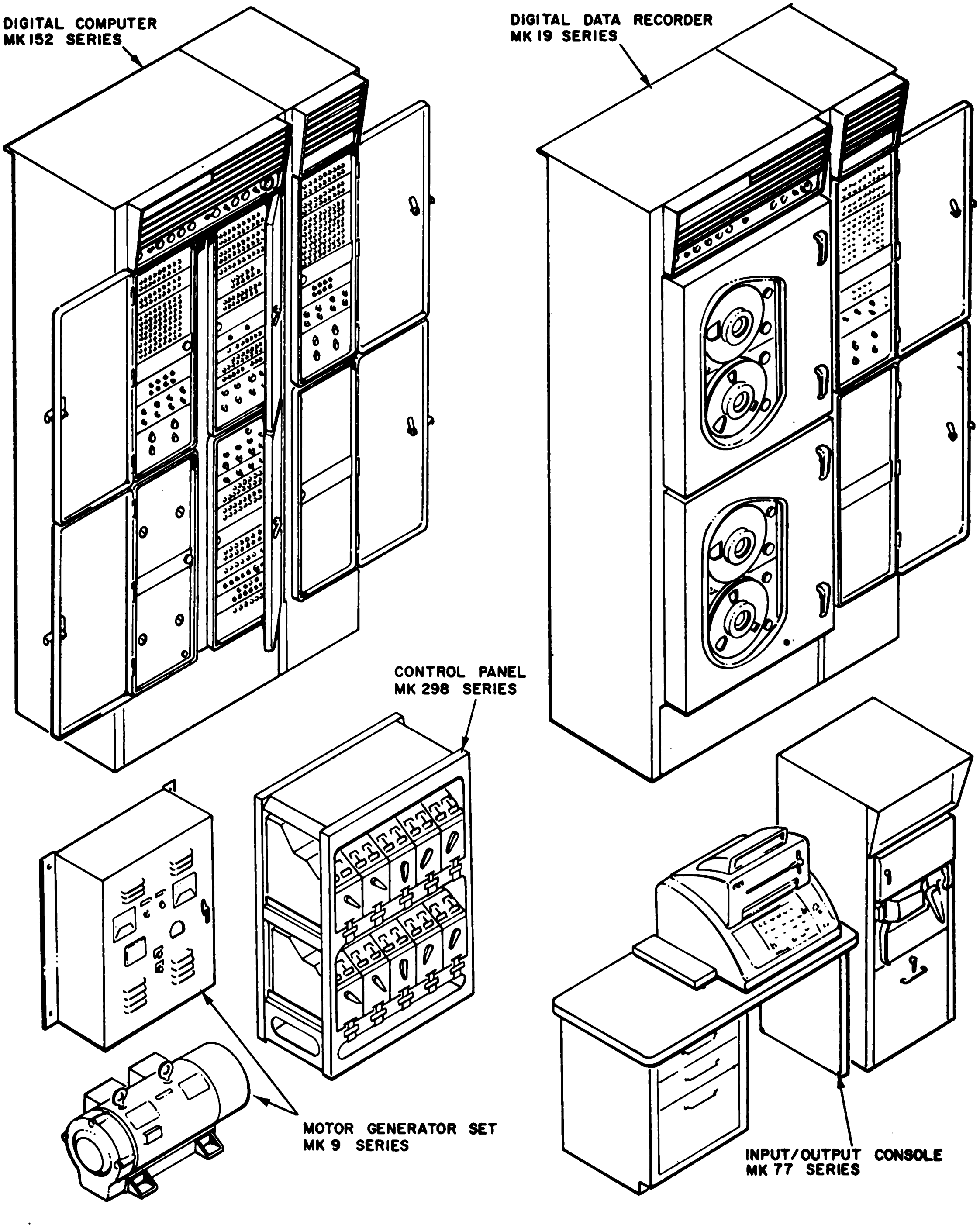

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Figure 7-31.—Computer equipment in common usage.

VEAPONS SYSTEM RELATIONSHIP

You will remember from your study of chapter hree that a typical shipboard weapons system omprises several subsystems, including (1) a Fire Control System (FCS), (2) a Weapon Direction System (WDS), (3) a Guided Missile Launching System (GMLS), and (4) guided missiles. Each of these subsystems is itself composed of one or more major pieces of equipment. The computer is one piece of major equipment hat functions within the FCS along with other najor equipment including the director and fire control radar set. Fire control systems utilizing various modifications of the Mk 152 computer eries are installed on many different ship lasses.

Computer Complex

Figure 7-30 is a block diagram of a typical omputer complex. Other ship classes have imilar configurations. The components which omprise the computer complex along with a brief escription of their functions are as follows:

- Digital Computer Mk 152 Series is the eart of the computer complex and interfaces irectly with all other units.
- Input/Output (I/0) Console Mk 77 is used rimarily to load into the computer through a eyboard or tape reader and to monitor data utputs from the computer through a tape perforator and printer.
- A Signal Data Converter (SDC) is shown ı figure 7-30. Some type of converter is used n all digital ships to allow communications etween the digital computer and weapons subsystem units.
- Digital Data Recorder (DDR) Mk 19 is large-capacity medium-speed storage system ith capability either of receiving data from the omputer and recording it on magnetic tape or retrieving data which has been previously ecorded on magnetic tape and transferring it the computer.
- Motor Generator Set Mk 9 converts 208 lts a-c 60 Hz 3-phase power or 416 volt a-c Hz 3-phase power to 115 volt a-c 400 Hz phase power for operating equipment comrising the computer complex.

omputer Group

The computer may be connected to a variety peripheral equipment including any of the llowing devices:

Paper-tape reader-punch units
Magnetic-tape systems
High-speed printer units
Card reader-punch units
Teletype printer units
Display and display interface units
Radars and radar adapter units
Manual entry devices

It is impractical to describe in this chapter all possible peripheral equipment which are, or could be, connected to the computer. Consequently, figure 7-31 depicts only the most commonly used computer group equipment.

DESCRIPTION

The Mk 152 digital computer is capable of solving any problem liable to solution by standard mathematical techniques; it can also perform most data processing functions. Logic in the Mk 152 computer is divided into four functionally definable sections discussed previously in this chapter. They are control, arithmetic, memory, and input/output as depicted in figure 7-1.

The Mk 152 digital computer in the Tartar fire control system, as an example, is housed in a single cabinet that contains the power supply, logic circuits, core memory, maintenance, and control panel, and a cooling system. Logic modules are encapsulated printed circuit cards which plug into the wired chassis of easily accessible pull-out drawers. The front of each drawer is the associated portion of the computer control panel.

Using designation data, the computer generates orders to drive the director to the designated target position. If needed, the computer initiates a search pattern to enable the radar to acquire the target. During tracking, the computer generates tracking rates for the director and, on the basis of tracking data, generates launcher and missile orders that program the missile for flight toward a predicted point of intercept. The computer also controls pulse repetition rate and radiofrequency decisioning for the fire control radar. In addition, the computer supplies engagement data to the Weapon Direction System.

Signal Data Converter Mk 72 in the interface between the existing analog portion of the fire control system and the Fire Control Computer Mk 152. Operating under computer control, it performs analog-to-digital and digital-to-analog conversions. The converter's design allows for expansion or adaptation to other systems.

CHAPTER 8

FUNDAMENTALS OF FIRE CONTROL RADARS

Radar is a term derived from Radio Detection And Ranging, and signifies a method whereby radio waves are employed to detect the presence and location of objects in space.

Target detection is accomplished by transmitting a beam of high-frequency energy over the area to be searched or scanned. When the energy strikes a reflecting surface, a small portion of the energy is reflected or reradiated toward the original radiating source, where a sensitive receiver located near the transmitter detects the echo pulse and, therefore, the presence of the target.

To determine the target's position in space, it is necessary to find its three positional coordinates (range, bearing angle, elevation angle) within a required frame of reference.

In this chapter we will first discuss special circuits and devices used in fire control radars followed by a presentation of the principles and fundamental elements that make a fire control radar system perform.

SPECIAL CIRCUITS AND DEVICES

We will now examine special circuits such as counting circuits, coincidence circuits, and time-delay circuits, along with basic principles of the cathode-ray, direct-view storage, magnetron, klystron, and traveling wave tubes.

If you have any trouble understanding the subject matter presented in this chapter, it will be to your benefit to study or to review Basic Electronics, NAVPERS 10087-C.

COUNTING CIRCUITS

The positive diode counter circuit is used in timing or counting circuits which depend upon a proportional relationship between the output voltage and the number of input pulses. It may indicate frequency, it may count the r.p.m. of a shaft or other device, or it may register a number of operations. The diode counter establishes a direct relationship between the input frequency and the average d-c voltage. As the input frequency increases the output voltage also increases; conversely, as the input frequency decreases the output decreases. In effect, the positive diode counter counts the number of positive input pulses by producing an average d-c output voltage proportional to the repetition frequency of the input signal. For accurate counting, the pulse repetition frequency must be the only variable parameter in the input signal. Therefore, careful shaping and limiting of the input signal is essential to insure that the pulses are of uniform width, or time duration, and that the amplitude is constant. When properly filtered and smoothed, the d-c output voltage of the counter may be used to operate a direct reading indicator.

The basic solid-state counter circuit is shown in figure 8-1A. Solid-state and electron tube counters operate sufficiently similar to warrant simultaneous treatment. (To change figure 8-1A to an electron tube circuit, diode tube symbols would be used in place of CR1 and CR2 and would be labeled V1 and V2.)

Capacitor C1 is the input coupling capacitor. Resistor R1 is the load resistor, across which the output voltage is developed. For the purpose of circuit discussion, it is assumed that the input pulses are of constant amplitude and time duration, and that only the pulse repetition frequency changes.

As shown in figure 8-1B, at time t_0 the positive going input pulse is applied to C1 and causes the anode of CR2 to go positive. As a result, CR2 conducts and current i_c flows through R1 and CR2 to charge C1. Current i_c develops an output voltage (e_o) across R1 as shown.

The initial heavy flow of current produces a large voltage across R1, which tapers off exponentially as C1 charges. The charge on C1 is determined by the time constant of load resistor R1,

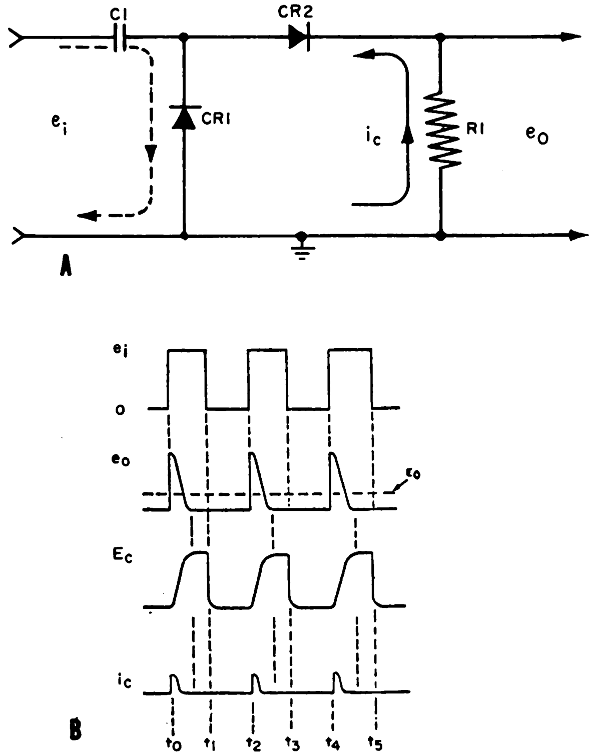

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Figure 8-1.— Positive diode counter and waveforms.

the conducting resistance of the diode, in series, and the capacitance of C1. For ease of explanation, it is assumed that C1 is charged to the peak value before t_1.

At time t_1 the input signal reverses polarity and becomes negative going. Although the charge on the capacitor C1 cannot change instantly, the applied negative voltage is equal to or greater than the charge on C1 so that the anode of CR2 is made negative, and conduction ceases. When CR2 stops conducting, output pulse e_O is at zero, and C1 quickly discharges through CR1 since its cathode is now negative with respect to ground (anode is grounded). Between times t_1 and t_2 the input pulse is again at zero level, and CR2 remains in a nonconducting state. Since the very short time constant offered by the conduction resistance of CR1 and C1 is much less than the long time constant offered by CR2 and R1 during the conduction period, C1 is always completely discharged between pulses. Thus, for each input pulse there is a precise level of charge deposited on C1. For each charge of C1 an identical output pulse is produced by the flow of i_c through R1. Since this current flow always occurs in the direction indicated by the solid arrow (fig. 8-1A), the d-c output voltage is positive with ground.

At time t_2 the input signal again goes positive, and the cycle repeats. The time duration between pulses is the interval represented by the period between t_1 and t_2 or between t_3 and t_4. If the input pulse frequency is reduced, these time periods become longer. On the other hand, if the frequency is increased, these time intervals become shorter. With shorter periods, more pulses occur in a given time and a higher average (d-c) output voltage is produced; with longer periods, fewer pulses occur and a lower average output voltage is produced. Thus, the d-c output is directly proportional to the repetition frequency of the input pulses. If the current and voltage are sufficiently large, a direct reading meter can be used to indicate the count; if they are not large enough to actuate a meter directly, a d-c amplifier may be added. In the latter case, a pi-type filter network is inserted at the output of R1 to absorb the instantaneous pulse variations and produce a smooth direct current for amplification.

Consider now some of the limits imposed on solid-state circuit operation. Since the semiconductor diode has a finite reverse resistance, there is a flow of reverse current during the periods when the diode is supposedly in a nonconducting condition. Although this reverse flow is small at normal temperatures (on the order of microamperes), it increases as the temperature rises. Therefore, at high temperatures the average output voltage will tend to decrease because of the effects of diode CR2.

From the preceding discussion it is evident that the voltage across the output varies in direct proportion to the input pulse repetition rate. Hence, the average current through R1 increases or decreases as the pulse repetition rate (frequency) increases or decreases. In order for the circuit to function as a frequency counter, some method must be employed to utilize this frequency to voltage relationship to operate an indicator. The block diagram in figure 8-2A represents one simple circuit which may be used to perform this function. In this circuit, the basic counter is fed into a low pass filter, which controls an amplifier with a meter calibrated in units of frequency.

A typical schematic diagram is shown in figure 8-2B. The positive pulses from the counter

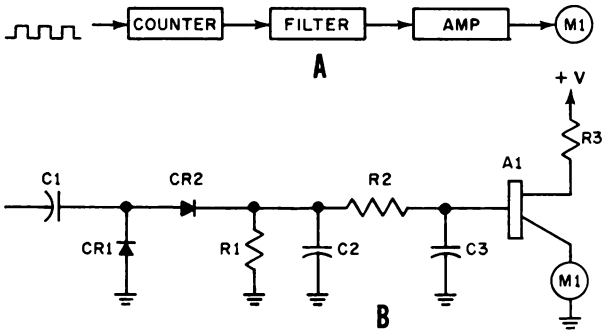

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Figure 8-2.— Basic frequency counter.

are filtered by C2, R2 and C3. The positive d-c voltage from the filter is applied to the input of A1. This voltage increases with frequency, and as a consequence the current through the device increases. Since emitter or cathode current flows through M1, an increase in amplifier current causes an increase in meter deflection. The meter may be calibrated in units of frequency, revolutions per minute, or any function based upon the relationship of output voltage to input frequency.

The step-by-step counter is used as a voltage multiplier when it is necessary to provide a stepped voltage to any device which requires such an input. The step-by-step (or step) counter provides an output which increases in one-step increments for each cycle of input. At some predetermined level, the output voltage reaches a point which causes a circuit, such as a blocking oscillator, to be triggered.

A schematic diagram of a positive step-by-step counter is shown in figure 8-3A. With no signal applied to the input, there is no output. As the input signal is applied, and increases in a positive direction, the anode of CR2 or V2 becomes more positive than its cathode, and the diode conducts. When CR2 or V2 conducts, capacitors C1 and C2 begin charging.

The action of the counter can best be understood by referrring to figure 8-3B. Assuming C2 to be ten times as large as C1 and the peak to peak input voltage to be 100 volts, C1 assumes nine-tenths of the positive input voltage swing at t_0, while C2 assumes only one-tenth or, in this example, 10 volts. At time t_1, the input drops in a negative direction, and CR2 or V2 is driven into cutoff. The cathode of CR1 becomes more negative than its anode, and the diode conducts, discharging C1. The charge on C2 remains, however, because it has no discharge path. Thus, there is a d-c voltage at the output which is equal to one-tenth of the input.

At time t_2, the input again increases positively, but this time CR2 cannot conduct until the input becomes greater than 10 volts, the charge on C2. At this level, CR2 conducts and C2 again charges to one-tenth of the total available voltage. The total voltage available at this time, however, is no longer 100 volts, but 100 volts minus the 10-volt charge on C2.

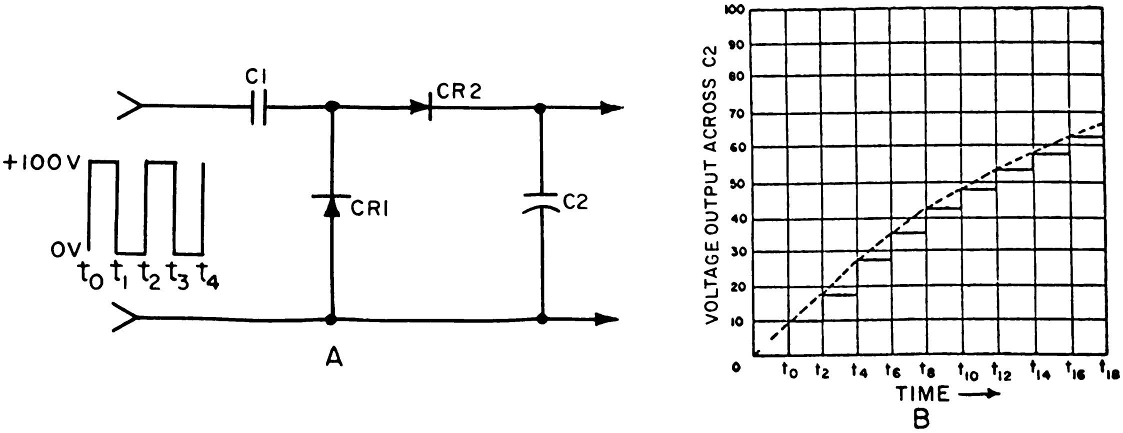

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Figure 8-3.—Basic step counter circuit and waveforms.

Thus, the first cycle of input produced a 10-volt charge on C2, but the second cycle added only an additional 9 volts, which is one-tenth the quantity of 100 volts minus the 10-volt charge on C2. Each additional cycle provides an exponential increase in the same manner. It is for this reason that the accuracy decreases as the ratio increases. Thus, as the ratio becomes too great, the higher steps become almost indiscernible. When the counter is used to trigger a blocking oscillator, such as the one shown in figure 8-4, the oscillator bias is adjusted by the potentiometer R2. This changes the amount of emitter or cathode voltage which determines the step that will cycle the blocking oscillator. When the oscillator draws current, it discharges C2 and the cycle repeats. The step counter, therefore, becomes a frequency divider supplying one output trigger for a number of input triggers.

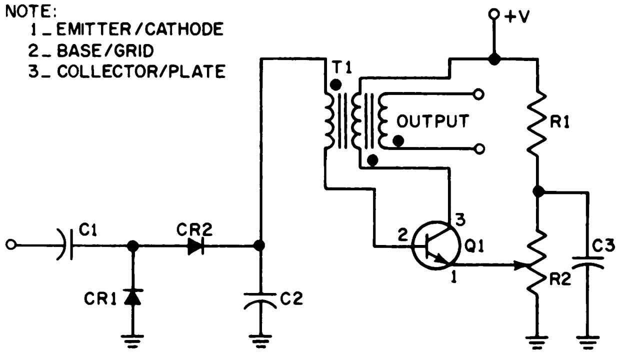

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Figure 8-4.—Counter triggering blocking oscillator circuit.

Explicit explanation of this circuit varies with driving source reference levels and type of output load circuit. For example, the input waveform may only vary above and below a zero reference in contrast to the waveform in figure 8-3 which only varied in a positive direction from the zero reference. Figure 8-5 illustrates this input and the resulting output.

Note that the step at t_2 is higher in amplitude than the step at t_0 in contrast to the smaller increments in amplitude illustrated in the description of figure 8-3. This is because at t_0, 50 volts is applied and C2 charges to one-tenth this value. At t_1, C1 not only discharges its 45-volt charge, but it charges to 50 volts in the opposite direction, through CR1. At t_2, the input again goes to the positive 50-volt level and will be additive to the 50 volts across C1. C2 will charge an additional 9.5 volts, since this is 10% of the 100 volts applied minus the 5-volt charge already on C2. Thus, at t_2, the charge on C2 reaches 14.5 volts.

Succeeding charges will be 10% of the 100-volt charge minus the existing charge on C2 at that time. Therefore, the output is affected because the initial input charge was only half the total peak charge. However, if C2 is discharged by a circuit such as the blocking oscillator just mentioned, the second staircase waveform will be like that in the initial description (fig. 8-4). This is because C1 now has a 50-volt negative charge from preceeding alternations so that on the next positive going charge after C2 is discharged, the full 100-volt swing is felt across the circuit.

Another condition may exist when the input swings both positive and negative around a zero reference. This condition occurs if the initial alternation swings in the negative direction,

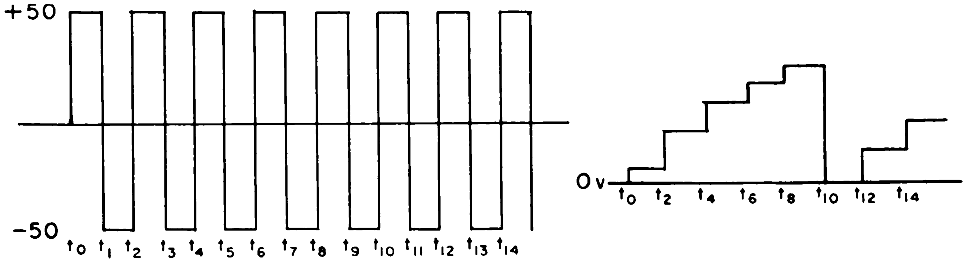

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Figure 8-5.—Input waveform varying about zero and resulting output.

charging C2 through CR1, thus providing the entire 100-volt potential on the first positive swing or second alternation. Other first cycle conditions will exist if the input only goes negative with respect to a zero reference. These examples illustrate the variety of first cycle conditions that may be encountered.

As previously mentioned, counting stability is dependent upon the exponential charging rate of C2. When it is desired to count by a large number, for example — 24, a 6:1 counter and a 4:1 counter connected in cascade may be used. A more stable method of counting 24 would be to use a 2:1, a 3:1 and 4:1 counter in cascade. Most step counters operate on ratios of 5:1 or less. The waveforms of a 4:1 frequency divider are shown in figure 8-6.

A solid-state step-by-step counter which uses tunnel diodes is shown in figure 8-7A. Resistor R1 sets the bias for CR1 through CR5 in their low voltage state. Positive pulses coupled through C1 sequentially switch the diodes to their high voltage state. The first pulse turns on CR1, the second CR2, the third CR3, the fourth CR4, and the fifth CR5. When CR5 goes to its high voltage state, Q1 is biased into conduction. Consequently, the voltage from the collector of Q1 to ground is reduced to a value which will cause the diodes to revert to their low voltage state, allowing the cycle to repeat.

Figure 8-7B shows the various voltage waveforms in the circuit. C2, C3 and L1 provide a slight delay which allows CR5 to complete switching to its high voltage state before Q1 conducts and recycles the operation. A five-step positive going stairstep voltage waveform is developed at the output. Details of tunnel diodes are discussed in chapter 15 of Basic Electronics, NP 10087-C, Volume 1.

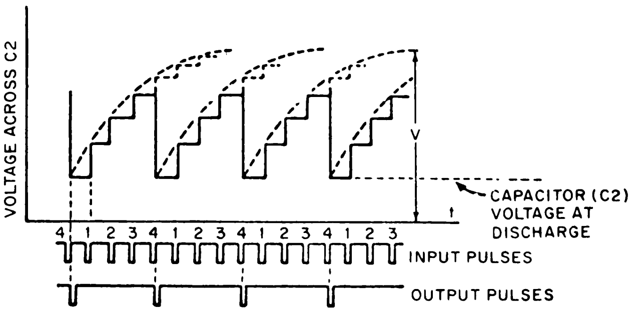

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Figure 8-6. — Voltage across C2 in a 4:1 counter.

COINCIDENCE CIRCUITS

A coincidence circuit produces an output only when each of its selected inputs is of sufficient amplitude, proper polarity, and concurrent in time with its desired mate or mates.

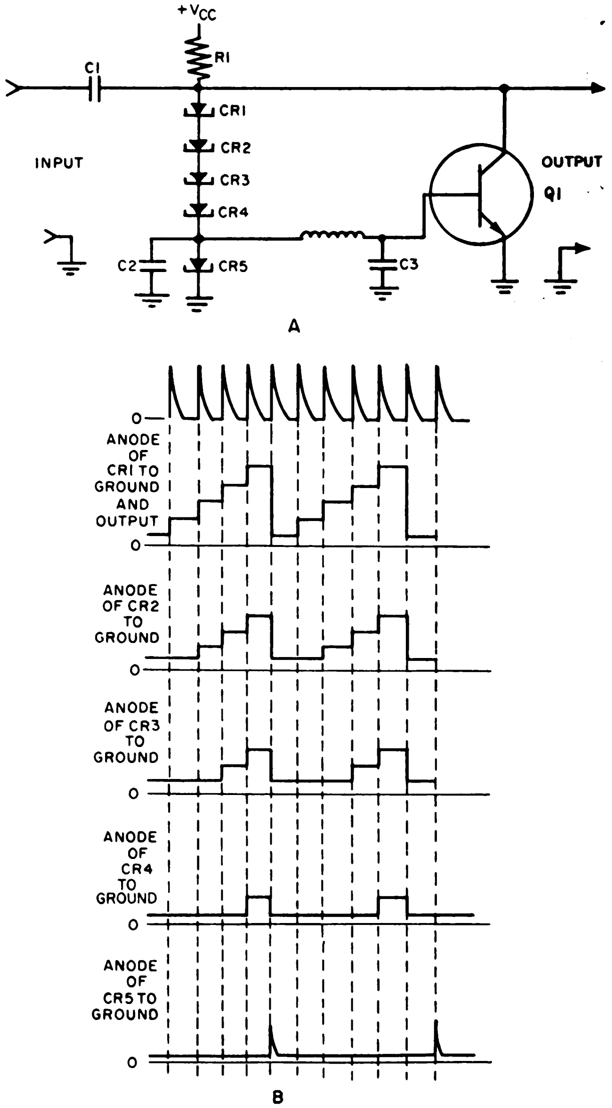

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Figure 8-7. — Positive tunnel diode step-by-step counter and waveforms.

Coincidence circuits are also known as AND GATES when used in digital logic applications.

Figure 8-8 depicts a three-input coincidence circuit and its associated waveforms. The polarities shown are correct for NPN transistors and electron tubes. For PNP transistors all polarities would be reversed. all polarities are referenced to ground unless otherwise noted.

All the devices are connected in series, and are biased into cutoff. There can be no current flow until all the devices are caused to conduct. During the period of time all inputs are sufficiently positive, the devices conduct heavily. This conduction produces a negative going pulse at the output. If any one input is absent, no amplifier current flow is possible, and the output will be simply some constant value of positive voltage.

Figure 8-9A illustrates a pentode electron tube coincidence circuit. The control grid and suppressor grid are biased sufficiently negative with respect to the cathode to allow either grid to hold the tube cut off. As shown in figure 8-9B, positive voltages must exist simultaneously, on both the control grid and suppressor grid, in order for the tube to conduct.

TIME-DELAY CIRCUITS

Time-delay circuits (delay circuits) are special control circuits used in various electronic systems, particularly in radar systems. These circuits are used to delay a waveform, which in turn produces a delayed action. The more common types of delay circuits are the RC, the phantastron, and the delay line (artificial lines).

RC Delay Circuit

In the RC delay circuit (fig. 8-10) the V1 control grid is connected to a positive voltage and V1 normally conducts heavily. Thus, plate voltage is low and C2 is charged to this low voltage. The input to V1 is derived from a multivibrator timer and is a negative square wave. The leading edge of this square wave is time zero, and it is at this time that the circuit is triggered. The leading edge of this square wave cuts off V1

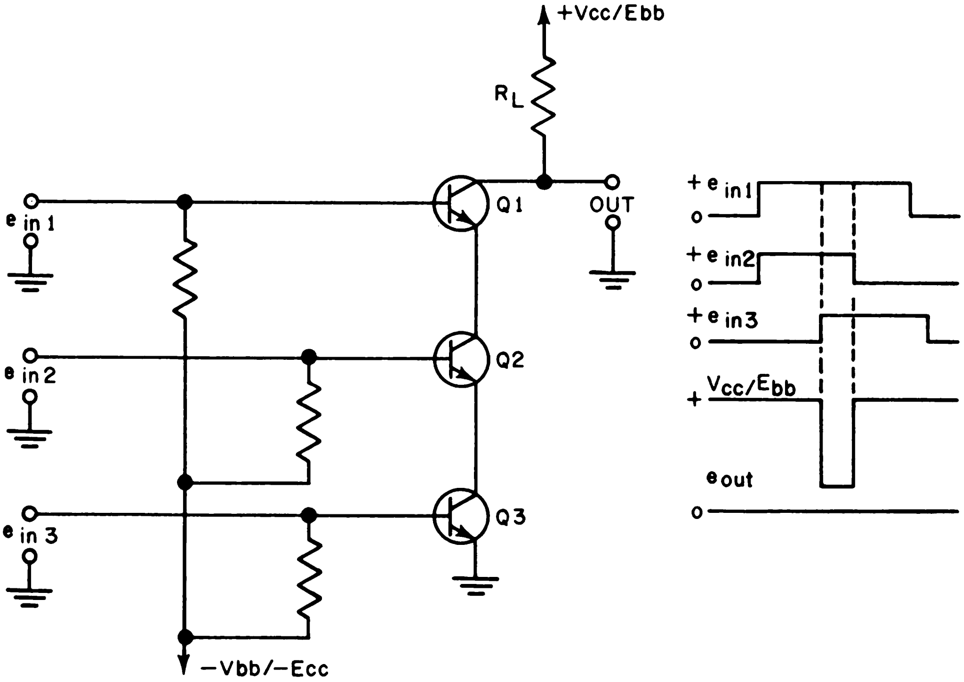

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Figure 8-8.—Basic coincidence circuit and waveforms.

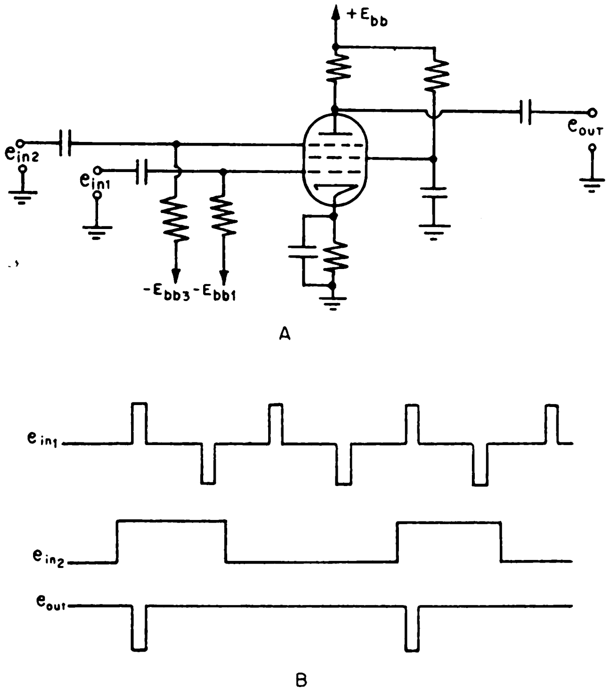

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Figure 8-9.—Pentode electron tube coincidence circuit and waveforms.

which was normally conducting. Plate voltage of V1 cannot rise instantly because of the time required to charge C2. Although C2 charges at an RC rate, during the first 10 percent of time the change in voltage is linear. V2 is normally cut off by a voltage divider network in the grid circuit which places a minus 19.5 volts on the grid. The linear change in voltage at the plate of V1 is coupled to the grid of V2 causing it to go positive and overcome its bias. The delay is a function of the bias applied to the grid of V2 and the rate of charge of C2. When the bias is overcome, V2 conducts and the blocking oscillator action produces a pulse output. A positive pulse output may be taken from the cathode and a negative pulse from across the plate load resistor. The blocking oscillator action in the grid circuit charges both C2 and C3 in a negative direction. This causes the plate voltage of V1 to decrease and keeps V1 from again triggering V2 immediately. Before C2 can again become positively charged to the point that it can trigger V2, the short RC in the grid of V1 has allowed V1 to conduct. Therefore, the circuit has returned to the static condition of V1 conducting heavily and V2 cut off.

Phantastron Circuit

The phantastron circuit is used to generate a rectangular waveform, or linear sweep, whose duration is almost directly proportional to a control voltage. Because of its extreme linearity and accuracy, this waveform is used as a delayed timing pulse, usually in radar or display equipment. It is also used to produce time-delayed trigger pulses for synchronizing purposes and movable marker signals for display. The phantastron circuit may be considered a special type of multivibrator circuit.

In the basic phantastron circuit (fig. 8-11), V1 may be thought of as a double triode with the plate, grid 3, and the cathode serving as one section, and grids 2 and 4, grid 1, and the cathode, serving as the second section.

Before a trigger is applied, the triode section comprising grids 2 and 4, grid 1, and the cathode is conducting. Grid 1 is returned to B+ through R5, which limits the grid 1 current to a low value, and grid 1 is at cathode potential.

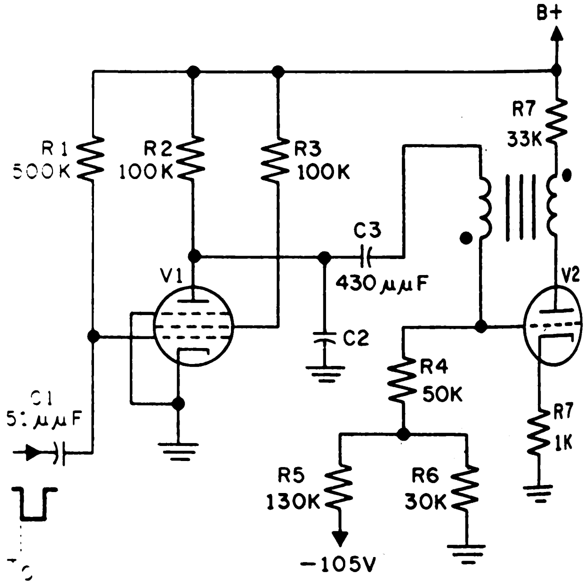

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Figure 8-10.—RC delay circuit.

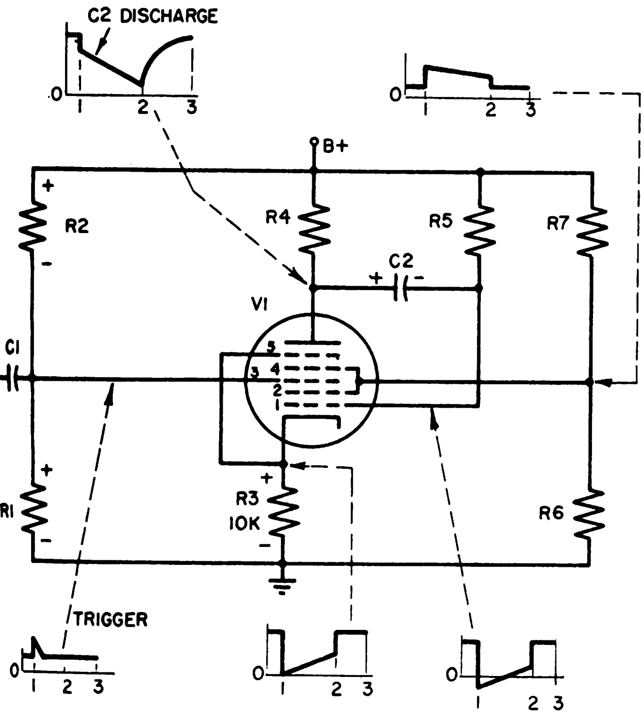

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Figure 8-11.—Basic phantastron circuit.

The triode section comprised of the plate, grid 3, and the cathode, is cut off. This cutoff is due to the relationship of R1, R2, and R3. The voltage across R1 is less than that across R3, making grid 3 negative with respect to the cathode.

A positive trigger on grid 3, at time 1, causes plate current to flow, and the voltage across R4 causes the plate voltage to drop from the B+ value. Initially, C2 is charged to the B+ voltage (the voltage across R5). When plate current flows, the voltage across R5 exceeds the B+ value by an amount equal to the drop across R4. This action causes the voltage of grid 1 to swing in a negative direction the same amount as the decrease in plate voltage.

The reduction in grid 1 voltage causes the screen grid (2-4) current to drop to almost cutoff. The net decrease in cathode current lowers the cathode voltage to almost zero. The plate resistor, R4, is relatively high in resistance so that the plate current is limited to a small part of the total cathode current.

This action permits plate current to flow without affecting the screen cutoff bias on grid 1 for the period between time 1 and time 2 even after the initiating trigger through C1 has been removed.

During the interval from time 1 to time 2, C2 discharges through R5, and the voltage on grid 1 slowly rises (the drop across R5 decreases with the decrease in voltage on C2). This action causes plate current to rise and plate voltage to fall as C2 continues to discharge. When the plate voltage falls to a low value, electrons begin to flow to the screen grid instead of to the plate. This action causes plate voltage to stop falling (at time 2) and to begin to rise. C2 couples this rise to grid 1 and quickly returns the grid 1 voltage to its original value.

While the grid 1 voltage returns quickly to normal at time 2, plate voltage increases slowly to the B+ level during the interval from 2 to 3 as C2 charges through R4 (long time constant, R4C2). This action is a disadvantage in that a relatively long time must pass before another trigger can be applied.

By connecting the plate of V1 to the grid of a cathode follower, V2, the variations of the plate voltage can be reproduced across the cathode resistor, R8 (fig. 8-12) and the charge path of C2 (through V2) will have a short time constant (R3C2). Capacitor C2 is now connected between grid 1 of V1 and the cathode of V2. This allows C2 to charge quickly through the low resistance of the cathode follower circuit. The discharge path of C2 is through the grid return resistor, R5.

The addition of the diode limiter, V3, to the basic phantastron circuit permits the width of the output pulse (the plate voltage variation between points 1 and 2) to be varied. The plate and control grid of V3 are tied together to form the diode plate. The cathode of V3 is connected to the arm of the potentiometer that is connected, in turn, between B+ and ground.

For one setting of the potentiometer arm the plate voltage is limited to this value. Because the plate of V1 is connected to the grid of V2, the voltage to which C2 can be charged is also limited to the value determined by the setting of the potentiometer arm.

The width of the output pulse depends upon the length of time it takes for capacitor C2 to discharge from the plate voltage at time 1 to a low value (a few volts) at time 2. The higher the initial voltage setting on the potentiometer arm, the longer the pulse width will be. As C2 discharges (following the application of a positive trigger voltage on grid 3), the V1 plate voltage falls. This action makes the V3 diode plate negative with respect to its cathode so that it does not conduct, and the V1 plate is not "caught" but is free to follow the voltage decrease on

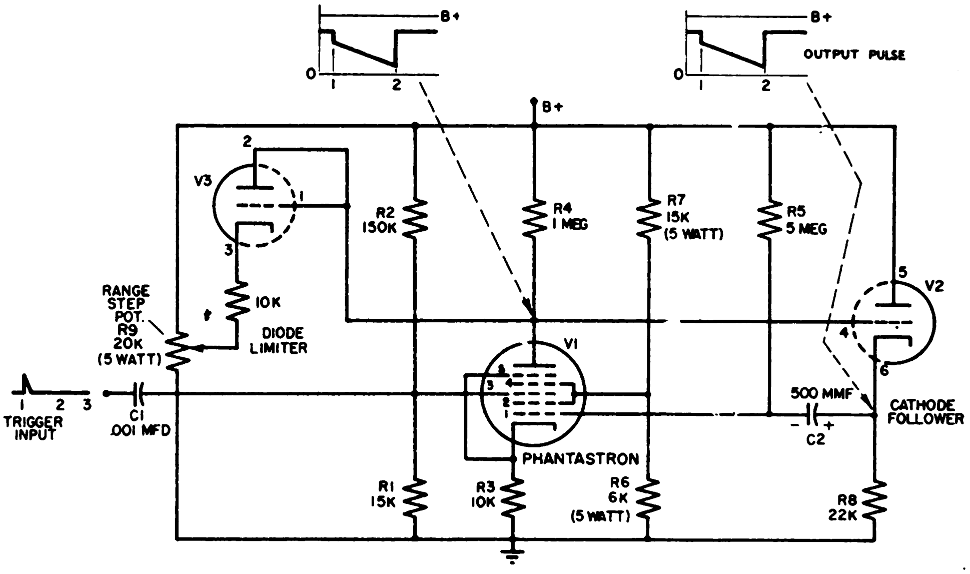

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Figure 8-12.—Modified phantastron circuit.

the V1 plate. At the end of the pulse, the V1 plate voltage rises but cannot exceed the voltage on the potentiometer arm except by a slight amount.

This action causes the V3 plate to be positive with respect to its cathode so that V3 conducts through R4, which holds the V1 plate voltage to approximately the voltage at the potentiometer arm.

Delay Lines

Artificial delay lines (sometimes referred to as artificial transmission lines) operate by virtue of the finite velocity with which the signal travels along the delay line. For open-wire lines there is practically no difference in the velocity of propagation of the signal as compared with the velocity of propagation in free space, so that multiples of a physical quarter-wavelength of line must be used to produce the delay. This results in long and bulky lines. Therefore, artificial lines consisting of lumped values of inductance and capacitance are connected together in low-pass filter arrangements as shown in figure 8-13, to provide the desired characteristics. Since a real transmission line has uniformly distributed inductance and capacitance, artificial lines can, in a small space, provide the electrical equivalent of a long line.

The manner in which the artificial delay line is used in a circuit determines how it functions. There are three forms of operation. One form is that of a simple delay line which delays the input pulse or signal by a period of time equal to the time it takes to traverse the line; in this case the termination of the signal initiates circuit action after a predetermined delay time. In the second form, the input pulse or signal is permitted to traverse the line, be reflected, and return to the origin, before circuit action is initiated. In the third form the line is charged to a specific storage level and is then discharged to form a precise pulse with a duration equal to the discharge-delay period. In each of these forms of operation, performance is generally based upon the theory of charge and discharge of an ideal lossless transmission line.

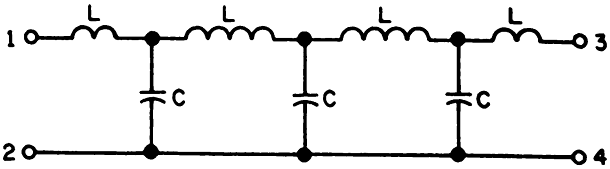

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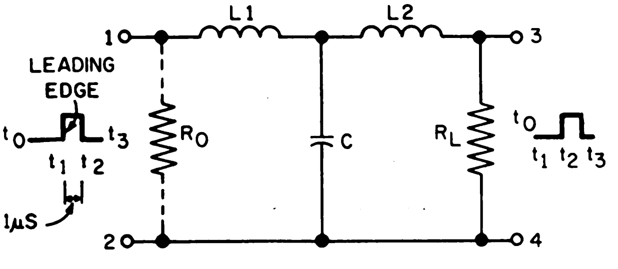
Figure 8-13.— Lumped-constant delay line.

In the case of the simple delay line, the line is terminated in its characteristic impedance (the input need not be terminated unless power transfer is required, since there is no reflection). Assume the simple balanced T section equivalent circuit as shown in figure 8-14. As far as the input circuit is concerned, the artificial transmission line appears as though it were a resistor equivalent to the characteristic (surge) impedance of the line (R_0). Assume that a rectangular 1-microsecond pulse is applied, and that a delay of 1 microsecond is desired. (The delay line is usually placed in series with the grid of a trigger circuit.) Let us also assume that a negative trigger is required to initiate action.

At the beginning of the cycle (time t_1), the positive pulse is applied to the line input at terminals 1-2. Immediately, the voltage across the line input rises to the pulse value (input is unterminated). At the load end of the line, however, no voltage as yet appears. Since the line constants are chosen for a 1-microsecond delay, it takes this length of time for the initial pulse to travel to the end of the line (because of the relatively low velocity of propagation of the line). During this interval, capacitor C is being charged through inductor L1. At time t_2 (1 microsecond later), capacitor C is charged and the pulse voltage now appears at output terminals 3-4, across RL. Note this is still the leading edge of the initial pulse. At time t_2 the initial pulse terminates and the input voltage across terminals 1-2 drops to zero. Capacitor C now discharges through inductor L2 until time t_3. When time t_3 is reached, the capacitor is completely discharged and the voltage across RL drops to zero. Thus, 2 microseconds after the start of the initial pulse, the negative trailing edge of the pulse appears at the grid of the trigger tube, and the trigger is initiated (by the trailing edge of the pulse) with a 2-microsecond delay.



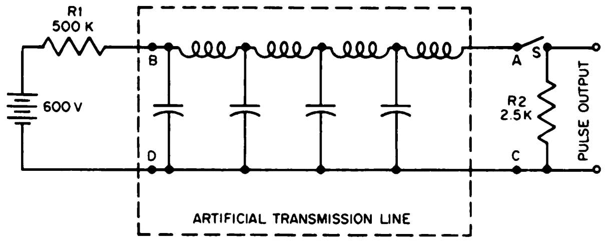
20.456

Figure 8-14. — Terminated delay line.

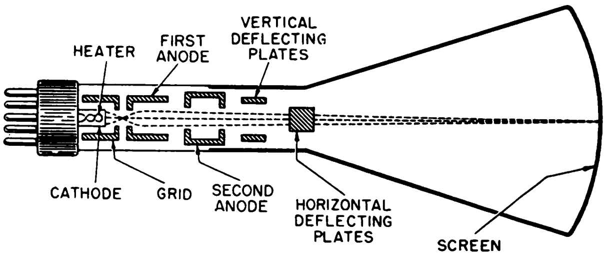
In practice, a number of sections of L and C are required to provide pulse transfer and delay without distortion.

A simplified circuit for producing a rectangular pulse by the use of an artificial transmission line is shown in figure 8-15. The characteristic impedance of the transmission line is 2,500 ohms. The resistor, R2, across which the output pulse is to be developed is equal to this characteristic impedance. Resistor R1, through which the line is charged, is made very much larger than the characteristic impedance so that it is an apparent open circuit during the discharge of the line. The capacitors are all charged to 600 volts if switch S is left open for a sufficient time. If the switch is closed after the line has been charged, a current immediately starts to flow through R_2. The line may be considered as a battery with an internal impedance of 2,500 ohms during the discharge time. The voltage across R_2 is one-half the voltage to which the line was charged, or 300 volts, since half the available voltage is lost across the 2,500-ohm internal impedance. If the network consisted only of capacitors, the discharge would follow an exponential curve, and the voltage across R_2 would not be constant. However, the inductance and capacitance of the line are so designated that the discharge rate is practically constant.

The discharge of the artificial line can be explained best as follows: At the instant that the switch S (fig. 8-15) is closed, the voltage at point A falls to 300 volts. This can be looked upon as a traveling wave of -300 volts applied at point A to reduce the voltage there immediately from 600 to 300 volts. As the wave moves from A to B the voltage across the line is reduced from 600 to 300 volts. On reaching point B, the wave sees an open circuit, since resistor R_1 is very large. The wave is reflected without change in sign, and immediately reduces the voltage at point B from 300 volts to zero as the wave travels back to point A; and the remaining 300 volts across the line is canceled out. On reaching point A, the wave has reduced the voltage across all sections to zero, the wave itself disappearing because it is absorbed by a load which matches the characteristic impedance of the line. The pulse formed across R_2 by the line discharge lasts for the time required for the traveling wave to move from the switch end of the line to the open end and back.



109.97
Figure 8-15.—Simple circuit for producing pulses.



20.320
Figure 8-16.—Construction of cathode-ray tube using electrostatic deflection and focusing.

CATHODE-RAY TUBES

The cathode-ray tube (CRT) is a special type of electron tube in which electrons emitted from the cathode are shaped into a narrow beam and accelerated to a high velocity before striking a phosphor-coated viewing screen. The screen fluoresces or glows at the point where the electron beam strikes and thus provides visual waveforms of current and voltage. The CATHODE-RAY OSCILLOSCOPE is a test instrument which uses the cathode-ray tube. The waveforms can be positioned on the screen so they appear stationary because the electron beam repeatedly reproduces the pattern in the same location, provided the horizontal motion of the electron beam is kept in step with the frequency of the signal.

The comparison is made against waveforms located on the schematic diagrams. Scope patterns periodically taken at the test points are compared with these waveforms. Differences between the optimum waveform and the scope pattern indicate that corrective action is needed. By using the oscilloscope in this manner, difficulties may be pin-pointed to a specific circuit or portion of a circuit in a short time.

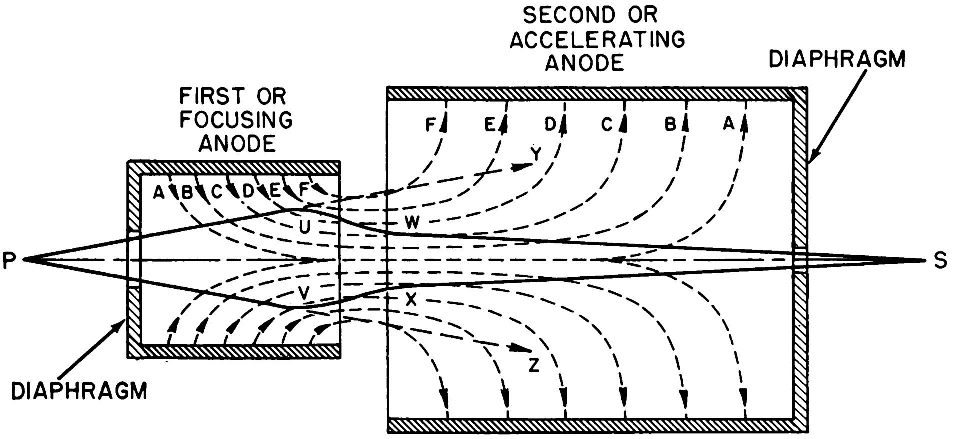
The CRT is also used as the visual indicating device for radar, sonar, radio, direction finders, loran, and television.

The beam of electrons has practically no weight or inertia but follows a straight line unless diverted by an electric or a magnetic field. Cathode-ray tubes are of two types according to the method of deflecting the electron beam—(1) electrostatic, and (2) electromagnetic. Almost all types of test-instrument oscilloscopes use the electrostatic type of CRT because of the need for high sweep frequencies in both the vertical and horizontal directions. Certain radar, sonar, and TV sets use electromagnetic type CRTs. Focusing or narrowing of the beam is achieved by either electrostatic or electromagnetic methods. Electrostatic deflection bends the beam by an electric field produced by a deflection voltage between parallel plates inside the CRT. Electromagnetic reflection bends the beam by means of a magnetic field produced by a deflection current in a coil around the neck of the tube.

An electrostatic type of CRT is illustrated in figure 8-16. The cathode, when heated by its enclosed filament, releases free electrons. A cylindrical grid surrounds the cathode and controls the beam intensity as electrons pass through the end opening of the grid. The control is achieved by varying the negative voltage on the grid in respect to the cathode and is called INTENSITY or BRIGHTNESS CONTROL. After leaving the grid, the electron stream passes through two or more cylindrical focusing anodes which narrows the beam. The first anode concentrates the free electrons and the second anode increases their speed. The entire assembly is called the ELECTRON GUN. The electrons emerge from the electron gun at high speed.

The grid helps to narrow the beam but cannot focus it to a sharp point on the viewing screen. The two anodes aid in the focusing action, as shown in figure 8-17.

Both cylindrical anodes are positive with respect to the cathode but the second anode is positive with respect to the first anode. Thus, an electric field is established between the anodes as shown in figure 8-17. The electrons which are emitted from the cathode are attracted by the first anode. Some of the electrons pass through the hole in the end of the first anode and into the field between the two anodes. The



20.321

Figure 8-17.—Electrostatic focusing.

purpose of the diaphragm is to prevent all electrons except those making a small angle with the axis of the beam from passing through the hole in the diaphragm. This serves to keep the beam narrow. The electrons entering the curved electric field between the anodes are subjected to inward-directed forces thereby focusing the beam. As the beam passes parallel to the lines of force, the electrons are accelerated to a very high speed. Thus, the net result of the forces influencing the beam of electrons is a high speed inward-directed beam converging at point S on the screen. The repelling force of like charges tends to scatter the electrons but they are accelerated to such a high speed that the scattering action is not effective in defocusing the beam. Nevertheless the mutual repulsion between electrons in relation to the speed of the electrons determines the sharpness with which a beam may be focused on the screen. The diaphragm on the accelerating anode is used to stop all wide angle electrons from hitting the screen.

The focus of the electrostatic type of cathode-ray tube is generally controlled by varying the voltage between the first anode and the cathode. This voltage varies the force exerted on the electrons and tends to narrow the beam. Thus, f the screen is observed when the first anode voltage is varied, the beam may be brought to a bright sharp spot.

Focusing in an electromagnetic cathode-ray ube is achieved by a coil encircling the outside neck of the tube. The coil may be moved along the neck to a limited extent to initially focus the beam, but the usual method, after the focus coil is in the proper position, is to vary the current flowing through the coil with a variable resistor. The term "focus control" is derived from this function.

Without lateral deflection, the electron gun produces only a small spot of light on the viewing screen. With deflection, the trace of the spot forms a line on the screen. The electrostatic-type of cathode-ray tube uses two pairs of deflection plates mounted at right angles to each other, as shown in figure 8-18. The vertical deflection plates (YY') deflect the beam vertically and the horizontal deflection plates (XX') deflect

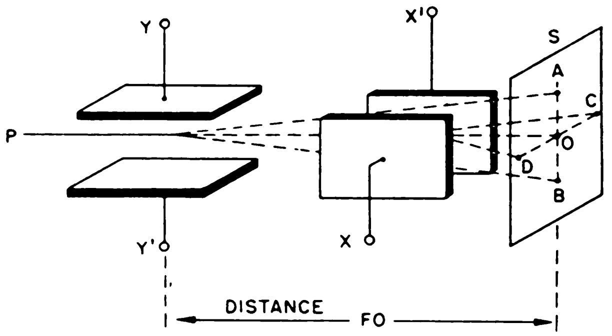


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Figure 8-18.—Deflection plates for electrostatic cathode-ray tube.

it horizontally. Both pairs usually function simultaneously. The beam is attracted by the positive plate and repelled by the negative plate as the electrons pass between them. One plate of each pair may be grounded. To deflect the beam, a positive or negative voltage is applied between the other plate and ground, thus establishing an electric field between the plates. The deflecting force varies with the deflection voltage across the plates and with the field intensity.

If plate Y is positive with respect to Y' the beam is deflected upward, striking the screen at A. If plate Y is negative with respect to Y' the beam is deflected downward, striking the screen at B. If there is no deflection voltage across the plates, the beam will strike the screen at 0. The amount of deflection varies with the deflection voltage across the plates. Note the relationship between length of line and voltage. This characteristic makes the CRT practical as a scope to serve as a voltmeter because the length of line (so produced) is a measure of the applied voltage.

Another practical use of the scope is for determining polarity. If plate X is positive with respect to X' the beam will be deflected horizontally, and will strike the screen at C. If X is negative with respect to X' the beam will strike the screen at D. Both pairs of plates are mounted near the output end of the electron gun, with the vertical deflection plates farthest from the screen. Two centering controls (horizontal and vertical) enable the operator to move the spot as he desires, to any place on the screen. Each control customarily consists of a variable resistor that serves as a voltage divider to enable the centering action.

The deflection angle of the electron beam is the total angle through which the beam may be moved or diverted. A cathode-ray tube with a 50° deflection angle can deflect the beam at any angle that equals (or is less than) 25° from the center line.

The length of time that the screen glows, or fluoresces, at the point where the electron beam strikes depends on the material of the phosphor coating on the screen, and is known as SCREEN PERSISTENCE. Some cathode-ray tubes have a long persistence screen and others have a short one, depending on their use. The screen phosphors are designated by the letter "P" followed by a number. Most radar indicator cathode-ray tubes employ P1, P4, or P7 screen phosphors. The P1 and P4 phosphors have medium persistence and give off green and white light respectively. The P7 screen has long persistence and gives off yellow light.

All fluorescent materials have some phosphorescence, or afterglow, but the duration the afterglow varies with the material, as wel as with the amount of energy in the beam causin the emission of light. For oscilloscopes that to be used for observing nonrepeating phenom or periodic phenomena that occur at a low repetition ratio, a screen material on which the imag will linger is desirable. Where the image change rapidly, prolonged afterglow is a disadvantage because it may cause confusion on the screen

The eye retains an image for about one sixteenth of a second. Thus in a motion picture the illusion of motion is created by a series still pictures flashed on the screen so rapidl that the eye cannot follow them as separat pictures. In the cathode-ray tube the beam repeatedly swept across the screen and th series of adjacent spots appear as a continuou line. Thus the wave shape of an a-c voltag can be observed on the screen when the a voltage is applied to one pair of deflectio plates and simultaneously a second voltage appropriate characteristics is applied to th other pair of plates.

DIRECT-VIEW STORAGE TUBE

The direct-view storage tube (DVST) is special type of CRT which is replacing the convential CRT in many applications. The DVST use secondary emission of electrons to store image and provides a very bright display wi controlled persistence. The main difference between the DVST and the convential CRT is addition of a storage grid, a collector grid, an a viewing gun (fig. 8-19).

The storage grid is a fine mesh scre placed about 1/4 inch in back of the phosph

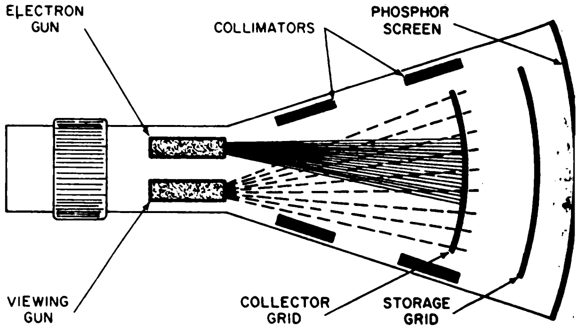

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Figure 8-19. — Direct-view storage tube.

screen. The side of the mesh toward the electron gun is coated with a dielectric material having a high secondary emission ratio at the electron gun voltage. When electrons from the electron gun strike the dielectric material, electrons are dislodged from the material thus leaving a net positive charge. A coarse mesh collector grid connected to a positive potential located near the storage grid collects the secondary electrons and keeps them from falling back on the storage grid.

The viewing gun is located near the electron gun and provides a flood of low-velocity electrons which fills most of the tube. Electrodes (called collimators) on the inside glass walls of the tube confine this flood of electrons from the viewing gun to a path parallel to the axis of the tube. Thus the electrons from the viewing gun are attracted by the positive potential on the collector grid and forced inward by the collimators to strike the storage grid perpendicular to the surface of the grid. The collimator voltages are adjusted so as to give a uniform flood of electrons over the entire storage grid surface.

Most of the electrons from the viewing gun pass through the collector grid to the storage grid. At points on the storage grid where electrons from the electron gun have left a positive charge, the viewing gun electrons pass through and are rapidly accelerated to the phosphor screen. At points on the storage grid where there is no stored positive charge, the potential is lower than the viewing gun potential and these points repel the viewing gun electrons. A very bright pattern is produced on the phosphor screen by a flood of low-velocity electrons rather than a beam of high-velocity electrons as in the conventional CRT. By varying the electron gun beam current, and thus varying the positive charge on the storage grid, the DVST can display four or five shades of grey in addition to black and white.

The DVST is erased by applying a positive pulse to the storage grid. The positive pulse causes the low-velocity electrons from the viewing gun to be attracted to the storage surface, charging the surface negative thus cutting off the viewing gun electron flow to the phosphor screen. Tube persistence is controlled by varying the duty cycle of the erase pulse.

KLYSTRON TUBES

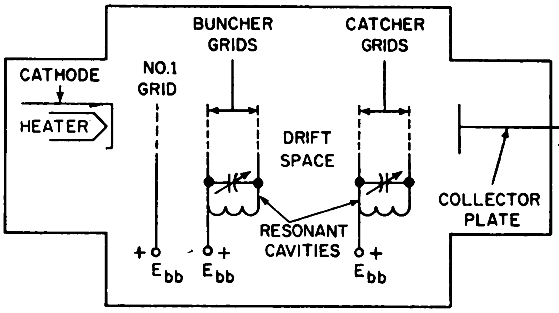

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Figure 8-20.—Basic klystron.

The klystron tube is a specially constructed electron tube using the properties of transit time and velocity modulation of the electron beam to produce microwave frequency operation. It can be used as an oscillator or an amplifier. The amplifier employes two or more cavities to produce the proper bunching of electrons, upon which its function and amplifying properties are based. The amplifier type of klystron can produce a large amount of power (up to megawatts) and can be used as an oscillator if proper feedback arrangements are made. However, the reflex klystron offers a simpler type of feedback arrangement and performs specifically as a special tube designed for oscillator operation alone. Although the power output of the reflex klystron is limited, it is adequate for receiving and test equipment functions and for low-power transmitters. Where high power is required, it can be achieved by using the reflex klystron as a master oscillator and the conventional amplifier type klystron as a power amplifier. Since microwave radiation is limited to line-of-sight distances, the reflex klystron usually furnishes sufficient power for these relatively short RF transmission paths.

The operation of the klystron is based upon the development of velocity modulation of the electron beam; that is, the velocity of the electron beam is controlled to produce a grouping or bunching of electrons. These bunches of electrons are then passed through grids or cavities to produce oscillations at the desired frequency by direct excitation of the cavities.

A basic klystron (not reflex type) is shown in figure 8-20. The electrons from the cathode are attracted to the accelerator grid (No. 1), which is at a positive potential with respect to the cathode. The accelerator grid may be a grid structure or an annular ring (cylinder or sleeve) through which the electrons pass unhindered. Assume that this attraction produces a constant-velocity electron beam, which is further attracted to the next electrode, the buncher grids (or cavity), and then to the next electrode, the catcher grids (or cavity), also at a higher positive potential. If the output from the catcher is fed back to the buncher, and if the proper phase and energy relations are maintained between the buncher and the catcher, the tube will operate as an oscillator. The collector plate, which is also at a positive potential, serves only to collect the electrons which pass the catcher. Successful operation requires that the energy needed for bunching be less than that delivered to the catcher. Amplifying action is obtained because the electrons pass through the catcher in definite bunches or groups as explained in the following paragraphs.

Bunching is produced by applying an alternating voltage to the buncher grids (produced by excitation of the buncher resonator by the passing electron beam). Assuming that a sine-wave voltage is produced and applied between the buncher grids, it is evident that on the positive alternation the buncher grid nearest the catcher effectively has its positive potential increased, and therefore further accelerates the electron flow. On the negative alternation, the same buncher grid voltage is made less positive and the electron stream is slowed down. Since a continuous stream of electrons enters the bunching grids, the number of electrons accelerated by the alternating field between the buncher grids on one half-cycle of operation is equalled almost exactly by the number of electrons decelerated on the negative half-cycle. Therefore, the net energy exchange between the electron stream and the buncher is zero over a complete cycle of alternation, except for the losses that occur in the tuned circuit (cavity) of the buncher.

After passing through the buncher grids, the electrons move through the drift space in the tube with velocities which have been determined by their transit through the buncher grids. Since in a conventional klystron the drift space is free of any fields, at some point in this drift space the electrons which were accelerated will catch up with those which were previously decelerated (in a prior passage) to form a bunch. The catcher grids are placed at this point of bunching (determined by frequency and transit time), to extract RF energy from the bunched electrons.

At the catcher a different situation exists. Since the electrons are traveling in bunches, spaced so that they enter the catcher field only when the oscillating circuit is in its decelerating half-cycle, more energy is delivered to the catcher than is taken from it. The remaining electrons in the beam pass through the grid and travel to the collector plate, where they are absorbed.

Multicavity Power Klystron Amplifier

In the above discussion, only a basic two-cavity klystron has been considered. This simple type of klystron amplifier is not capable of high gain, high output power, or suitable efficiency. With the addition of intermediate cavities and other physical modifications the basic two-cavity klystron may be converted to a multicavity power klystron. This amplifier is capable of high gain, high power output, and satisfactory efficiency. Figure 8-21 illustrates a multicavity power klystron amplifier.

In addition to the intermediate cavities, there are several physical differences between the basic and the multicavity klystron. The cathode of the multicavity power klystron must be larger, in order to be capable of emitting large numbers of electrons. The shape of the cathode is usually concave, to aid in focusing the electron beam. The collector must also be larger to allow for greater heat dissipation. In a high power klystron, the electron beam may strike the collector with sufficient energy to cause the emission of x-rays from the collector. Many klystrons have a lead shield around the collector as protection against these x-rays. Most high power klystrons are liquid cooled and must be constructed to facilitate the cooling system.

Klystron amplifiers have been built (to the present time) with as many as seven cavities (i.e., with five intermediate cavities). The effect of the intermediate cavities is to improve the bunching process. This results in increased amplifier gain, and to a lesser extent increased efficiency. Adding more intermediate cavities is roughly analogous to adding more stages to an IF amplifier. That is, the overall amplifier gain is increased and the overall bandwidth is reduced, if all the stages are tuned to the same frequency. The same effect occurs with klystron amplifier tuning. A given klystron amplifier tube will deliver high gain and narrow bandwidth if all the cavities are tuned to the same frequency. This is called SYNCHRONOUS TUNING. If the cavities are tuned to slightly different frequencies the gain of the klystron amplifier will be reduced and the bandwidth may be appreciably increased. This is called STAGGER

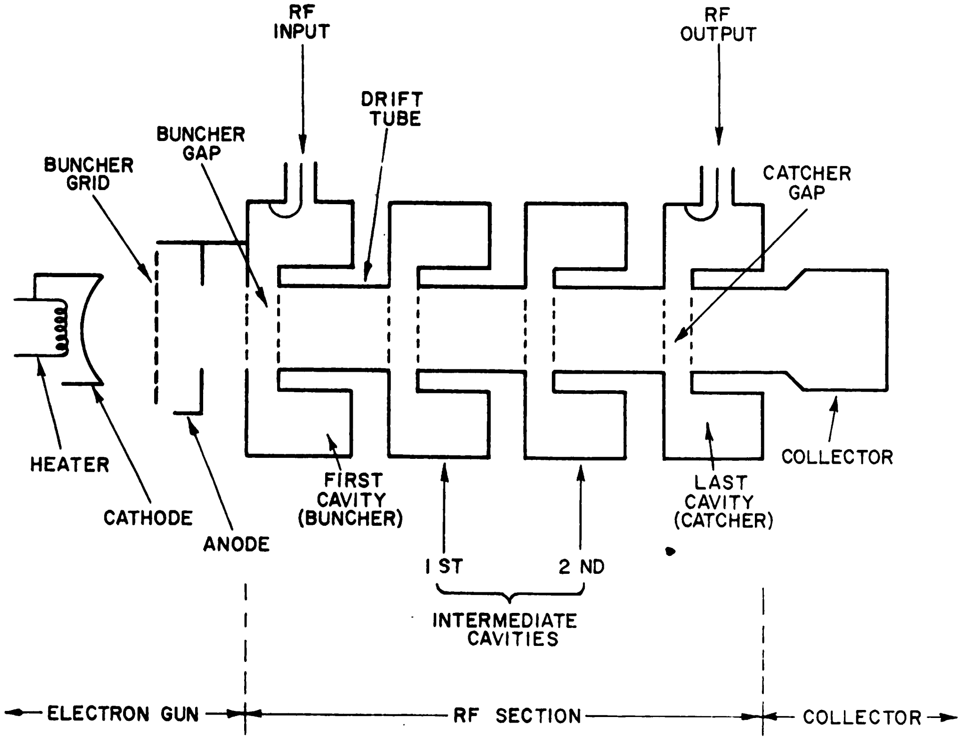

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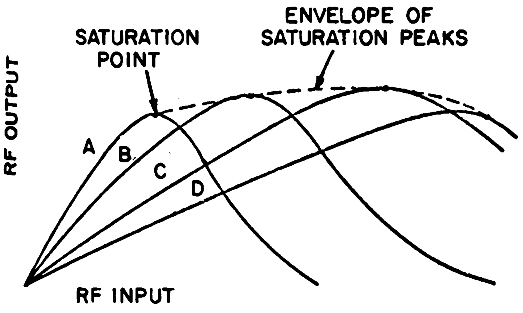
Figure 8-21.—Multicavity power klystron amplifier.

UNING. Most klystron amplifiers which feature elatively wide bandwidths are stagger tuned.

The klystron is not a perfectly linear ampliier. That is, the RF power output is not linearly elated to the RF power input at all operating levels. Another way of stating this is that the klystron amplifier will saturate, just as a triode amplifier will limit if the input signal becomes too large. In fact, if the RF input is increased to levels above saturation the RF power output will actually decrease. Figure 8-22 shows a plot of typical klystron amplifier performance for various tuning conditions. The RF output is plotted as a function of the RF input. Curve A of figure 8-22 shows typical performance for synchronous tuning. Under these conditions the tube has maximum gain. The power output is almost perfectly linear with respect to the power input, up to about 70 percent of saturation. However, as the RF input is increased beyond that point, the gain decreases and the tube saturates. As the RF input is increased beyond saturation the RF output decreases.



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igure 8-22.—Plot of typical klystron amplifier performance for various tuning conditions.

To better understand the reason for this decrease, recall that in the previous discussion, electron bunches were formed by the action of the RF voltage across the buncher cavity gap. This RF voltage accelerated some electrons and slowed down other electrons, resulting in formation of bunches in the drift tube region. Obviously, this speeding up and slowing down effect will be increased as the RF drive power is increased. The saturation point on figure 8-22 is reached when the bunches are most perfectly formed at the instant they reach the output cavity gap. This results in the maximum power output condition. When the RF input is increased beyond this point, the bunches are perfectly formed before they reach the output gap. That is, they form too soon. By the time the bunches have reached the output gap, they tend to debunch because of the mutual repulsion of electrons and because the faster electrons have overtaken and passed slower electrons. This causes the power output to decrease.

If a multicavity klystron power amplifier is synchronously tuned, and the next to last cavity is then tuned to a higher frequency, the gain of the amplifier is reduced, but the saturation power output level may be increased. This effect is shown by curves B and C of figure 8-22. Curve B represents a small amount of detuning of the next to last cavity, and curve C represents even more detuning. Note that the gain of the tube has been reduced, and that the saturation output power is higher than that obtained with synchronous tuning (curve A). Many klystron amplifiers are operated stagger tuned because of the resulting higher output power capability with the same beam power input. This increases the efficiency, provided, of course, that enough RF drive power is available to operate under the stagger tuned condition. Also, as mentioned previously, stagger tuning results in a wider amplifier bandwidth.

As might be expected, stagger tuning may be carried too far, at which point the saturation output power will drop. This is illustrated by curve D of figure 8-22.

Focusing

One very important item which is required for high power klystron amplifier operation is an axial magnetic field (i.e., a magnetic field parallel to the axis of the klystron). In klystron amplifiers which are physically long, it is quite difficult to keep the electron beam properly formed during its travel through the RF section. The mutual repulsion between electrons causes the beam to spread in a direction perpendicular to the axis of the tube. If this is allowed to occur electrons will strike the drift tube and be collected there, rather than passing through the drift tube to the collector.

To overcome beam spreading, an axial mag
netic field is used. The action of the magne
field is to exert a force on the electrons whi
keeps them focused into a narrow beam. Th
magnetic field may be developed by a permane
magnet or by one or more electromagnets.
permanent magnet is used on tubes which a
physically small or of medium power rating. U
fortunately, the size and weight of a perman
magnet are excessive for long or high pow
tubes, making it necessary to use electromagne
In some large tubes, several separate electr
magnets are used. The current in each coil
individually adjustable to optimize the magne
field shape. The magnetic field is norma
terminated a short distance beyond the out
cavity so that the beam may spread before
hits the collector. This tends to spread t
electron beam interception over a large surfa
on the collector, minimizing collector cooli
problems which would result from the bea
remaining concentrated at the time of inte
ception.

Even with an axial magnetic field, som
electrons will go astray and not remain in the ma
electron beam. These electrons will be inte
cepted by the anode or klystron drift tubes.
high power tubes it is particularly important
minimize the number of stray electrons, becaus
of the heat generated when they strike the dri
tubes. In a high power klystron this heating ma
be a very severe problem because drift tube
are very difficult to cool. Temperatures ma
become high enough to melt the drift tubes an
destroy the tube.

The collector is normally insulated from th
RF section of large klystron amplifiers to permi
separate metering of the electrons intercepte
by the drift tubes and those intercepted by th
collector. The electrons intercepted by the R
section are normally called BODY CURRENT
while electrons intercepted by the collector ar
normally referred to as COLLECTOR CURRENT
Obviously, the sum of body current and collecto
current is equal to the total current in the elec
tron beam, which is called BEAM CURRENT
Klystron amplifier specifications will quite ofte
place a maximum limit on allowable body cur
rent.

In the previous discussion of klystron opera
tion, it was implied that klystron amplifier
normally have actual metal grid structures acros
the gaps in the resonant cavities. Many lo
power klystrons do indeed have wire mesh grids
However, most high power klystrons do not hav

ctual grids across the gaps. Such grids would ntercept sizable quantities of electrons.

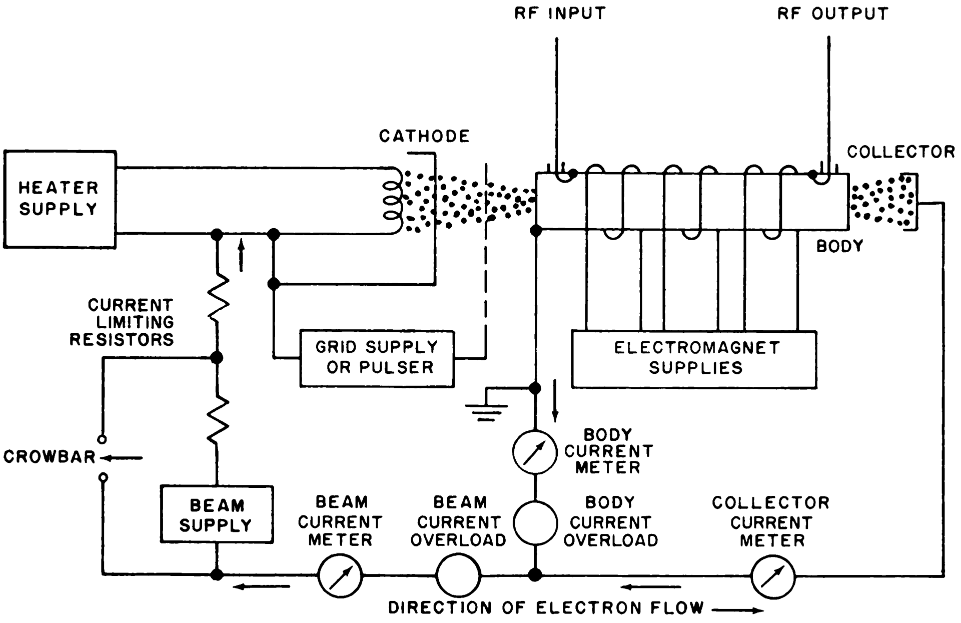
It is very difficult to cool grid structures, nd a large amount of beam interception would nelt the grids, thus destroying the tube. Forunately, by proper design the klystron may be nade to operate efficiently without actual grid ires across the cavity gaps. The absence of hese grids does not change the operating princiles discussed previously, but it does have a econdary effect on klystron performance. If he electron beam has a small diameter comared to the diameter of the drift tube, the beam oes not couple energy to the cavities very well. herefore, the performance of a klystron ampliier, which does not have gridded gaps, may ometimes be improved by permitting the elecron beam to be as wide as possible, while eeping the body current down to the maximum pecified for the tube. The width of the beam nay be somewhat controlled by the magnetic ield strength.

Body current usually increases with RF input evel because it is the RF input which causes he bunches to form. The dense electron concenration in the bunch causes mutual repulsion of lectrons, and the diameter of the bunch may beome larger than the diameter of the beam with no bunches present. Consequently, some of the electrons in the bunch may be lost to the drift tubes, and the body current may increase.

Associated Equipment

In the preceding sections the basic theory of klystron operation has been discussed. Considerable additional equipment is required for a complete amplifier system. Various power supplies are necessary, to deliver the required voltages and currents. In high power systems, a method of cooling is required. Various RF circuit components are required to control and measure the RF input to the klystron tube and to measure the RF output from the tube. A large collection of meters and protective devices are needed to monitor performance and protect operating personnel and equipment, in the event of a malfunction or operator error. Figure 8-23 is a simplified diagram illustrating some of the power supplies, monitoring devices, and protective devices used in a typical power klystron amplifier.

In most klystron tubes the anode and RF section are connected together inside the vacuum envelope. These parts are normally called the TUBE BODY, and are generally operated at ground potential. It is convenient to operate the tube body at ground potential because the input



179.726

Figure 8-23.—Associated klystron amplifier equipment.

and output connections (either waveguide or coaxial) are then also at ground potential. This makes it easier to connect the klystron into the rest of the system. In addition, the cavity tuners are at ground potential, eliminating any danger to personnel tuning the tube.

The beam supply shown in figure 8-23 supplies the voltage required to accelerate the electrons and form the beam. It must also deliver the required beam current. The crowbar system quickly discharges the beam supply in the event of an internal klystron arc, or other high voltage fault condition.

For high power systems, it is normal to have some value of series resistance between the beam supply and the klystron cathode. This limits tube current to a finite value if the tube should arc from cathode to ground.

Some klystrons have a grid or modulating anode which is used to control the number of electrons in the electron beam. Such grids are often used in pulsed systems to turn the tube full-on or full-off. A few systems employ grid modulation for the transmission of intelligence. In most gridded klystron tubes the grid is never allowed to go positive with respect to the cathode. This might cause undue grid interception of the beam and result in burnout of the grid element. A grid power supply is required in those tubes which have grids. These power supplies and pulsers may take many forms, depending on the system application, and will not be discussed here.

The collector of most high power klystrons is insulated from the body of the tube. This allows separate metering and overload protection for the body current and collector current. In most systems the collector and body operate at nearly the same potential. Any potential difference is normally only the difference in voltage drop across the various metering circuits.

Figure 8-23 shows three electromagnets wrapped around the body of the klystron. Some klystrons are made with the electromagnets physically part of the tube itself. However, in most systems the electromagnets are separate from the tube, and the klystron is inserted into the electromagnet structure. Many modern klystrons have only one electromagnet and therefore required only one power supply. Others may have as many as six separate coils requiring one power supply for each coil. Voltage and current metering is usually supplied for each of the electromagnet power supplies. If an electromagnet power supply should fail, the electron beam would almost certainly spread, and most of the beam current would be intercepted on small section of the drift tube. In most case this would cause the drift tube to melt and pe manently destroy the tube. Therefore, klystr amplifier equipment normally has under-curre protection in each of the electromagnet circuit When the magnet current falls below a pr determined level the beam supply is automaticall turned off to prevent damage to the klystro Redundant protection is provided by the bo current overload circuits which also turn off th beam supply in the event of magnet current failure or misadjustment.

Also shown in figure 8-23 is a method use to monitor body current, collector current, a beam current separately. In many systems sep rate monitoring of collector current is not do since the collector current and total beam cu rent are almost equal. It is quite unusual, in relatively high power klystron amplifier system to allow the body current to exceed 10 perce of the beam current. High body current usual means low efficiency and increases the dang of burning out drift tubes. In very high powe klystrons the body current is often limited to or 2 percent of the total beam current. Over current protection is almost always supplied fo both body current and beam current. If a klystr arcs internally, the arc will always occur b tween cathode and anode. When this occurs, th body current immediately becomes excessiv tripping out the body current overload relay An arc also causes beam current to be muc higher than normal, and the beam current overload will also trip out. In fact, almost any hig voltage system fault (such as an insulatio breakdown) will cause excessive current throug the body current meter and overload relay

Because of the possibility of extremely hig currents flowing under fault conditions, the protection of body current and beam current meter presents a somewhat difficult problem. This problem is usually solved by using very high curre solid-state rectifiers, back to back, across th meters. In some causes it is necessary to add small resistance or inductance in series with th meter. Surge capacitors are normally place across the combination. It is necessary to connect the rectifiers back to back because fau conditions often cause oscillating currents flow through the meters.

Klystron Mixer

In addition to its use as a power amplifie a klystron also may be used as a mixer. Heterodyning is accomplished in the electron beam

Jsually the original input frequencies consist f a high frequency signal and low frequency ignal. The high frequency signal is applied to he buncher cavity, while the low frequency ignal may be applied either to the cathode r modulating grid. The buncher cavity is tuned o as to be resonant to the original high freuency signal and the intermediate and catcher avities are tuned to the difference of the two riginal input frequencies.

lystron Modulation

In a pulsed microwave system using a power lystron, one of three methods may be used to ccomplish modulation. The first method is to witch the beam accelerating voltage on and off. he second is periodic interruption of the RF put signal. The last method is to turn the lystron beam current on and off.

When a klystron is pulsed by turning the ccelerating voltage on and off, the entire beam urrent must be pulsed as well. This action is imilar to modulating a magnetron, and requires modulator capable of handling the full power the beam.

When modulation is accomplished by switchg of the RF input signal, the beam current ust also be pulsed. If this is not done, beam wer will be dissipated, to no useful purpose, the interval between RF input pulses. This duces the efficiency of the tube.

Of the three methods, pulsing the modulating id or anode is the most commonly used.

RAVELING WAVE TUBE (TWT)

The traveling wave tube is a high gain, low ise, wide bandwidth microwave amplifier. TWT's are capable of gains of 40 db or more, with bandwidths of over an octave. (A bandwidth of one octave is one in which the upper frequency is twice the lower frequency.) TWT's have been designed for frequencies as low as 300 MHz and as high as 50 GHz.

The primary use for the TWT is voltage amplification (although high power TWT's, with characteristics similar to those of a power klystron, have been developed). Their wide bandwidth and low noise characteristics make them ideal for use as RF amplifiers in microwave and electronic countermeasures equipment.

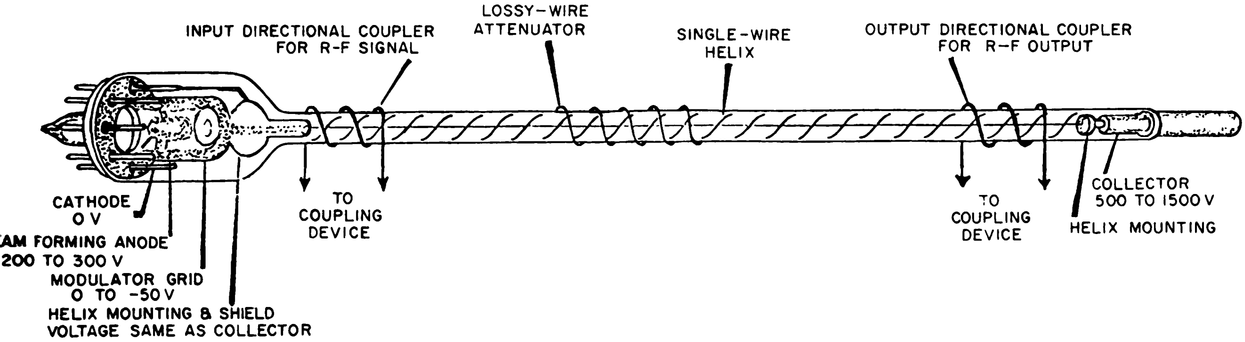
Construction

Figure 8-24 is a pictorial diagram of a traveling wave tube. The electron gun produces a stream of electrons which are focused into a narrow beam by an axial magnetic field, much the same as in a klystron tube. The field is produced by a permanent magnet or electromagnet (not shown) which surrounds the helix portion of the tube. The narrow beam is accelerated, as it passes through the helix, by a high potential on the helix and collector. The function of the helix will be discussed later.

Operation

Whereas the electron beam in a klystron travels, for the most part, in regions free from RF electric fields, the beam in a TWT is continually interacting with an RF electric field propagating along an external circuit surrounding the beam.

To obtain amplification, the TWT must propagate a wave whose phase velocity is nearly synchronous with the d-c velocity of the electron


INPUT DIRECTIONAL COUPLER FOR R-F SIGNAL
LOSSY-WIRE ATTENUATOR
SINGLE-WIRE HELIX
OUTPUT DIRECTIONAL COUPLER FOR R-F OUTPUT
CATHODE O V
AM FORMING ANODE 200 TO 300 V
MODULATOR GRID 0 TO -50 V
HELIX MOUNTING & SHIELD VOLTAGE SAME AS COLLECTOR
TO COUPLING DEVICE
TO COUPLING DEVICE
COLLECTOR 500 TO 1500 V
HELIX MOUNTING

179.728

Figure 8-24.—Pictorial diagram of a traveling wave tube.

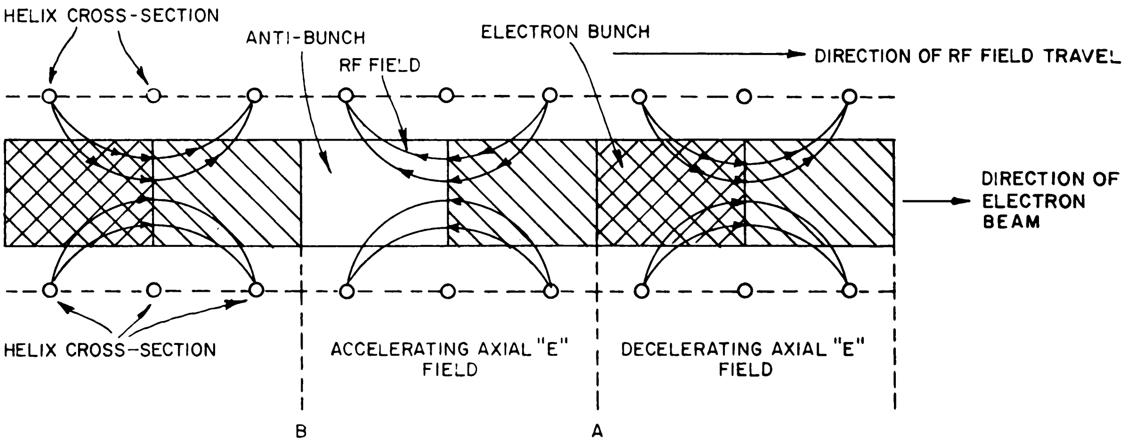
beam. It is difficult to accelerate the beam to greater than about one-fifth the velocity of light. Therefore, the forward velocity of the RF field propagating along the helix must be reduced to nearly that of the beam.

The phase velocity in a waveguide which is uniform in the direction of propagation is always greater than the velocity of light. However, this velocity may be reduced below the velocity of light by introducing a periodic variation of the circuit in the direction of propagation. The simplest form of variation is obtained by wrapping the circuit in the form of a helix whose pitch is equal to the desired slowing factor.

As previously explained, the electron beam is focused and constrained to flow along the axis of the helix. The longitudinal components of the input signal's RF electric field, along the axis of the helix or slow wave structure, continually interact with the electron beam to provide the gain mechanism of TWT's. This interaction mechanism is pictured in figure 8-25. This figure illustrates the RF electric field of the input signal, propagating along the helix, infringing into the region occupied by the electron beam.

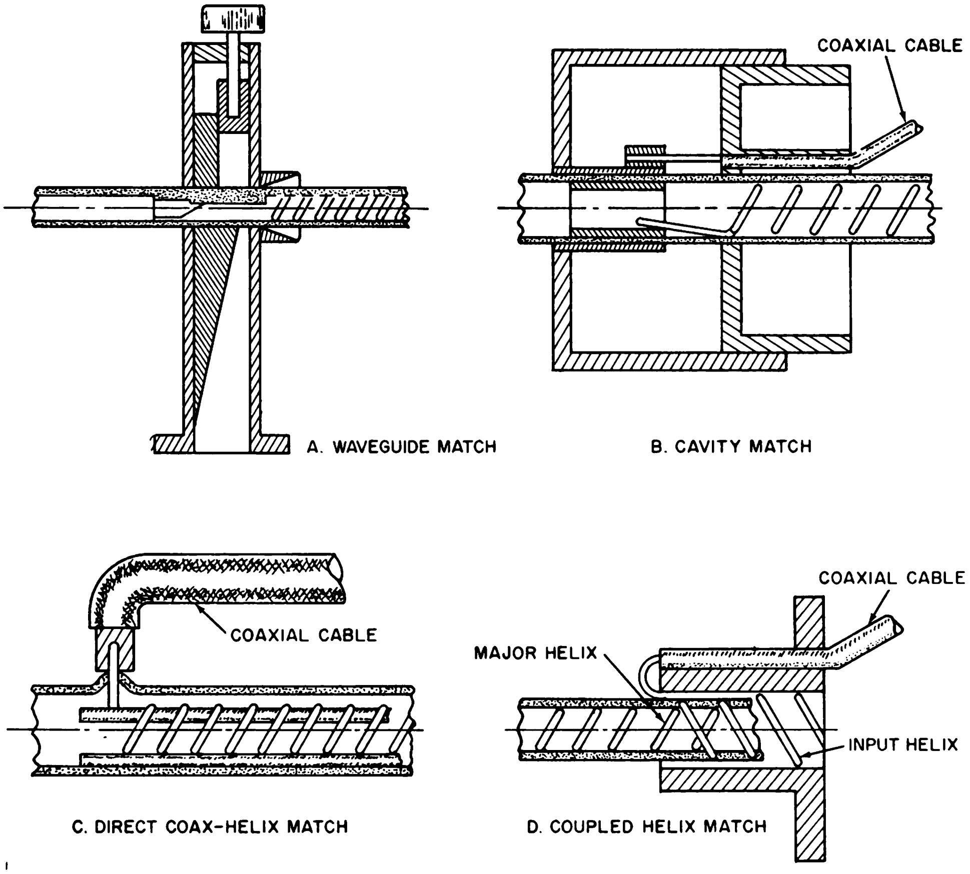
Consider first the case where the electron velocity is exactly synchronous with the circuit phase velocity. Here, the electrons experience a steady d-c electric force which tends to bunch them around position A, and debunch them around position B. This action is due to the accelerating and decelerating electric fields, and is similar to velocity and density modulation previously discussed. In this case, as many electrons are accelerated as are decelerated; hence, there is no net energy transfer between the beam and the RF electric field. To achieve amplification, the electron beam is adjusted to travel slightly faster than the RF electric field propagating along the helix. The bunching and debunching mechanisms just discussed are still at work, but the bunches now move slightly ahead of the fields on the helix. Under these conditions more electrons are in the decelerating field to the right of A than are in the accelerating field to the right of B. Since more electrons are decelerated than are accelerated, the energy balance is no longer maintained. Thus, energy transfers from the beam to the RF field, and the field grows.

Fields may propagate in either direction along the helix. This leads to the possibility of oscillation due to reflections back along the helix. This tendency is minimized by placing resistive material near the input end of the slow wave structure. This resistance may take the form of a lossy wire attenuator (fig. 8-24) or a graphite coating placed on insulators adjacent to the helix. Such lossy sections completely absorb any backward traveling wave. The forward wave is also absorbed to a great extent, but the signal is carried past the attenuator by the bunches of electrons. These bunches are not affected by the attenuator, and, therefore, reinstitute the signal on the helix, after they have passed the attenuator.


HELIX CROSS-SECTION
ANTI-BUNCH
RF FIELD
ELECTRON BUNCH
DIRECTION OF RF FIELD TRAVEL
DIRECTION OF ELECTRON BEAM
HELIX CROSS-SECTION
ACCELERATING AXIAL "E" FIELD
DECELERATING AXIAL "E" FIELD
B
A

179.729

Figure 8-25. — Helix field interaction.



179.730

Figure 8-26.—TWT RF coupling.

upling

Some means must be provided to apply RF ergy to one end of the helix and remove it m the other. Four methods of coupling are strated in figure 8-26.

Figure 8-26A illustrates waveguide matching. waveguide is terminated in a nonreflecting edance, and the helix is inserted into the eguide, as shown. The efficiency of the system ather good, but the waveguide has a far higher han the traveling wave tube. This means that broad band characteristics of the TWT suffer hat the entire bandwidth is not available for lification. The waveguide will not respond such a wide spectrum.

The cavity match, illustrated in figure 8-26B ery similar to the waveguide match. Cavities be made to resonate over wider ranges than eguides, but they still have a high Q compared to the TWT. The helix is placed at the mouth of the cavity, thereby absorbing any E-field produced. The RF is fed into the cavity by a coaxial cable.

Figure 8-26C illustrates a direct coax-helix match. It is the simplest system of all. The center conductor of the input coaxial cable is connected directly to the helix. Although this method is used quite frequently, it has a disadvantage. A high VSWR is set up by this match, and this causes heating around the input connection. Since this connection passes through the glass envelope, the envelope is subject to heating and breaking at this point. However, this is a major problem only in higher power TWT's.

Figure 8-26D illustrates the coupled helix match. In this system, the coaxial center conductor is attached to a small helix. The major helix is inserted within this input helix where it acts as the secondary of a transformer. This system has a good VSWR and is broader in bandwidth than cavities or waveguides, although it is unable to handle large amounts of power.

It should be noted, that any of the above coupling methods may be used for input as well as output coupling.

TWT Mixer

The traveling wave tube has also found application as a microwave mixer. By virtue of its wide bandwidth, the TWT can accommodate the frequencies generated by the heterodyning process (provided of course, that the frequencies have been chosen to be within the range of the tube). The desired frequency is selected by the use of a filter on the output of the helix. A TWT mixer has the added advantage of providing gain as well as simply acting as a mixer.

TWT Modulation

A TWT may be modulated by applying the modulating signal to a modulator grid. The modulator grid may be used to turn the electron beam on and off, as in pulsed microwave applications, or to control the density of the beam and its ability to transfer energy to the traveling wave. Thus, the grid may be used to amplitude modulate the output.

TWT Oscillator

A forward wave traveling wave tube may be constructed to serve as a microwave oscillator. Physically, a TWT amplifier and oscillator differ in two major ways. The helix of the oscillator is longer than that of the amplifier and there is no input connection to the oscillator.

The operating frequency of a TWT oscillator is determined by the pitch of the tube's helix. The oscillator may be tuned, within limits, by adjusting the operatng potentials of the tube.

Oscillator Operation

The electron beam, passing through the helix, induces an electromagnetic field in the helix. Although initially weak, this field will, through the action previously described, cause bunching of succeeding portions of the electron beam. With the proper potentials applied, the bunches of electrons will reinforce the signal on the helix. This, in turn, increases the bunching of succeeding portions of the electron beam. The signal on the helix is sustained and amplified by this positive feedback resulting from the exchange of energy between electron beam and helix.

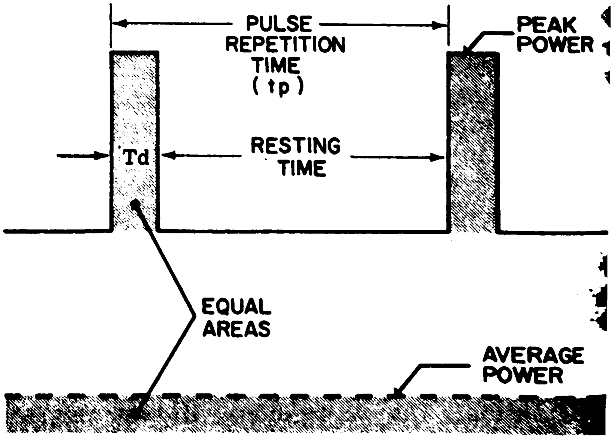
TYPES OF ENERGY TRANSMISSION

Radar systems employ two basic types of energy transmission: pulse and continuous wave (CW). The basic principle of pulsed radar is that the transmitter sends out radio waves in a series of short, powerful pulses and then rests during the remainder of its cycle. During the period in which the transmitter is at rest, echo signals may be received and timed to determine the range to the reflector surface (target). In CW radar, on the other hand, the transmitter sends out a continuous signal. If a nonmoving target is in the path of the transmitted wave, the frequency of the reflected signal will be the same as that of the transmitted signal. If the target is moving, the frequency of the reflected echo will differ from that of the transmitted signal due to the doppler effect, and the frequency difference can be used as an indicator of target motion. In CW transmission, either a movement of the radar or the target is necessary to produce an indication of target presence.

PULSE

Pulse radar makes it possible to measure range in terms of the time intervals between transmission of a pulse and the reception of an echo or reflected pulse from the target. The relationship of these pulses is shown in figure 8-27.

The pulse repetition time (tp) must be of sufficient duration to allow the echo pulse to return from the maximum range of the radar set.



167.7

Figure 8-27. — Pulse repetition time.

otherwise the reception of an echo will be obscured by the succeeding pulse. The total time required for the completion of a cycle (the pulse duration plus the resting time) is called the repetition time. The reciprocal of repetition time s the repetition frequency. The necessary time for an echo to return determines the maximum frequency which can be used for pulse repetition. The minimum range at which a target can be detected is determined by the pulse width, Td. If a target is so close to the transmitter hat the echo is received before the transmitter s cut off, the echo reception will be almost completely attenuated by the transmitted pulse. Because the pulse duration time must be short o increase reception of nearby targets and yet contain sufficient power to insure a return echo f sufficient magnitude from the maximum range f the radar set, extremely large transmitted power outputs are required. The useful power of he transmitter is contained in the radiated pulses nd is termed the peak power of the radar.

Since the radar is not transmitting for much f its total cycle, the average power is quite low, hen compared with the peak power during the ulse time. The relationship between average ower dissipated over the entire cycle and peak ower developed during the pulse time can be xpressed by the following equation:

$$\frac{\text{average power}}{\text{peak power}} = \frac{\text{pulse width (td)}}{\text{pulse repetition time (tp)}}$$

he greater the pulse width, the higher the verage power; the longer the pulse repetition me, the lower the average power. The relaonship between pulse width and pulse repetition me and between average power and peak power ay be expressed in duty cycles and represented s:

$$\frac{\text{pulse width}}{\text{pulse repetition time}} = \frac{\text{average power}}{\text{peak power}} = \text{duty cycle}$$

For example, a 2-microsecond pulse repeated a frequency of 5000 Hz, represents a duty ycle of .01, since the time for one cycle is 5000 of a second, or 200 microseconds.

$$\frac{2}{200} = .01 = \text{duty cycle}$$

Assuming a peak power of 200 kilowatts, r 2 microseconds, 2000 kilowatts are availle. Since average power = peak power x duty cycle then the average power = 2000 x .01 kilowatts = 20 kilowatts, as shown in figure 8-28.

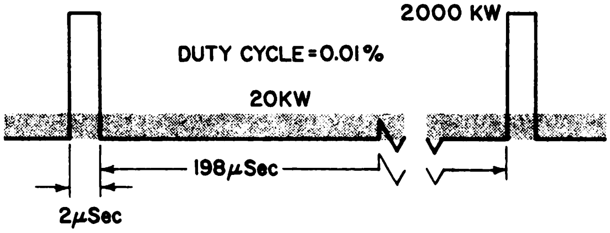


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Figure 8-28.—Duty cycle.

Range Determination

The effectiveness of range determination depends primarily on the ability of the radar to measure distance in terms of time. Electromagnetic radiation travels in space at a constant velocity of 186,300 miles per second. When it is reflected there is no loss in velocity, but merely a redirecting of the energy path. Range is then determined by the time required for a two-way energy transmission. The determination of range can be made by using the equation

$$R = \frac{ct}{2}$$

where R = the distance or range from radar set to target
c = the speed of propagation of radio waves in air
t = the time required for the two-way trip.

The velocity of electromagnetic radiation is approximately

1) 186,300 miles/sec
2) 984 ft/μsec
3) 328 yds/μsec
4) 6.18 μsec/nautical mile (using the approximation of 6000 ft equals one nautical mile).

Fire control radar sets determine distance in yards. Since the constant velocity of electromagnetic radiation is 328 yards per microsecond, a target located 32,800 yards from the radar set will require a round trip time of 200 microseconds. Since there are 1760 yards in a mile, the round trip time for a distance of one yard is 0.0061 microseconds. A more convenient figure is the round trip echo time for a target 1000 yards away-6.1 microseconds.

CONTINUOUS WAVE

When radio-frequency energy which is transmitted from a fixed point continuously strikes an object which is moving toward or away from the source of the energy, the frequency of the reflected energy is changed. This change in frequency is known as the Doppler effect, or shift. The difference in frequency between the transmitted and the reflected energy determines the presence and the speed of the moving target.

A common example of the Doppler effect is the changing pitch of the whistle of an approaching train. The train's whistle appears to change its pitch from a high tone as the train approaches to a lower tone as it moves away from the observer. As the train approaches, there is an apparent increase in frequency — a rising of the pitch; as the train moves away, there is an apparent decrease in frequency — a lowering of the pitch. This is the Doppler effect.

To examine the reason for this apparent change in pitch, assume that a transmitter emitting an audio signal at a frequency of 60 Hz is traveling at a velocity of 360 feet per second (fps). (See fig. 8-29.) Therefore, at the end of 1 second the transmitter will have moved from T to T1 in figure 8-29(A). The total distance from T to O, the position of the observer, is 1,080 feet. The velocity of sound is 1,080 feet per second. Thus, a sound emitted at T will reach O in 1 second. To find the wavelength (λ) of the transmitted signal, divide the velocity of the signal (1,080 fps) by the frequency of the signal (60 Hz). The result is 18 feet.

It is known that in 1 second the transmitter moves 360 feet and transmits 60 Hz. At the end of 1 second the first cycle of the transmitted signal reaches the observer just as the 60th Hz is leaving the transmitter at T1. Under these conditions the 60 Hz emitted are between the observer and T1. Notice that this distance is only 720 feet (1,080 - 360). The 60 Hz spread over the distance from T1 to O have a wavelength which is only 12 feet (720/60). To find the new frequency, use the formula for frequency:

$$f = \frac{V}{\lambda}$$

$$= \frac{1,080}{12}$$

$$= 90 \text{ Hz.}$$

The original frequency of 60 Hz has changed to an apparent frequency of 90 Hz. This new frequency only applies to the observer at O. Notice that the Doppler frequency variation is directly proportional to the velocity of the approaching transmitter. The faster the transmitter moves toward the observer, the greater the number of waves that will be crowded into the space between the transmitter and the observer.

If the transmitter were stationary and the observer moving, the observer would encounter more waves per unit of time as he approaches the transmitter. As a result, he would hear a higher pitch than the transmitter was actually emitting.

When the transmitter is traveling away from the observer, as in figure 8-29(B), the first cycle leaves the transmitter at T and the 60th at T2. The first cycle reaches the observer at O when the transmitter reaches T2. There are 60 Hz stretched out over 1,080 plus 360 feet, a total of 1,440 feet. The wavelength of these 60 Hz is 1,440/60, or 24 feet. Their apparent frequency is 1,080/24, or 45 Hz.

The Doppler shift has important operational applications aboard ship to determine target true motion. Since the Doppler frequency is a measure of velocity only, there is no way of measuring range directly at a constant carrier frequency. Tracking with CW radars is possible, theoretically, to zero range.

If a target is moving, its velocity, relative to the radar can be detected by comparing the transmitter frequency with the echo frequency, which will differ because of the Doppler shift. The difference or beat frequency, fd, sometimes called the Doppler frequency, is related to target

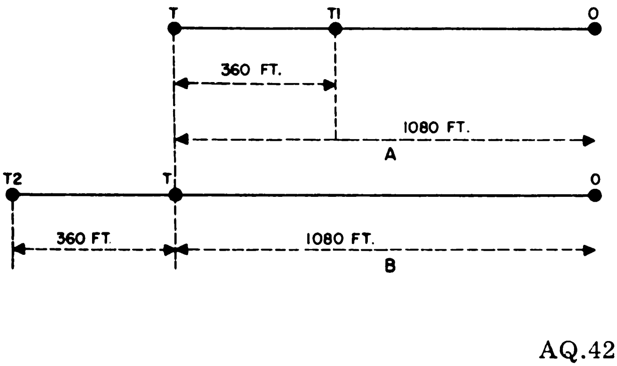

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Figure 8-29. — Transmitter moving relative to an observer.

elocity, v, and transmitted wavelength λ(in
m) as follows:

$$fd = 89.4\ v/\lambda$$

To track a target with CW Doppler radar,
ange information is required, but fd is not a
nction of range. However, if two separate
ansmitters operating at two frequencies f1 and
are employed, then the relative phase between
e two Doppler frequencies is a linear function
range to the target. In this system a hybrid
ixer is used to combine the two transmitted
equencies and separate the two received fre-
uencies to permit the use of one transmitting
d one receiving antenna.

Instead of two transmitter frequencies the
me result is achieved by sweeping the trans-
itter frequency uniformly in time to cover the
equency range from f1 to f2. The beat fre-
uency fd between the transmitted and received
gnals is then a function of range. In this type
radar the velocity as well as range is measured
that the velocity information, which is rate
change of range, can be used to control range
d velocity gates for range tracking.

ULSE-DOPPLER

Pulse radars may be modified in one of
veral ways to employ the target Doppler fre-
ency to detect a moving target. The Doppler
ift affects the transmitter pulse repetition fre-
ency (prf), pulse width, and carrier frequency,
d a pulse radar can be designed to recognize
e of these effects.

A requisite for any Doppler radar is coherence;
at is, some definite relationship must exist be-
een the transmitted frequency and the reference
equency which is used to detect the Doppler
ift of the received signal. The presence of a
oving target in a background of external noise
known from the amplitude variations the target
ho produces in the noise spectrum. Amplitude
tection employs noncoherent reception. Moving
rgets are also detected by the phase difference
tween the target signal and noise components.
ase detection employs coherent reception. In
ncoherent detection, phase changes are not in-
lved; and therefore, if the external noise
vel present is not too high, the target may be
stinguished visually from the noise clutter on
A-type or range scope of the radar set.

In coherent detection a stable CW reference
cillator signal, which is locked in phase with
transmitter during each transmitted pulse, is mixed with target echo signals to produce a beat signal. Since the reference oscillator and the transmitter are locked in phase, the echoes, in effect, are compared with the transmitter.

The phase relationship of the echoes from fixed targets to the transmitter is constant; therefore the amplitude of the beat signal remains constant. Beat signals of varying intensity indicate a moving target, because the phase difference between the reference oscillator signal and target signal changes as target range changes.

The beat signals are subtracted in the radar receiver, causing the fixed target signals, which are of constant amplitude, to cancel out. The signals from a moving target, which cause phase difference, do not cancel and are sent to the radar scope for display.

PRINCIPLES OF ENERGY TRANSMISSION

As a wave is propagated outward from the antenna, wavefronts form spherical surfaces that expand radially, figure 8-30. If the antenna is directional (which is almost always the case) the distribution of power over the wavefront surface is not uniform. The power density (power per unit area) is greater at points within the beam (A) and small at points on the extremities of the beam (B). Points of no radiation are called null points (C). The power density decreases gradually from a maximum at point A to zero at point C. The region of main radiation between C and C' is called the major lobe, and regions of low radiation are called minor lobes. The major lobe

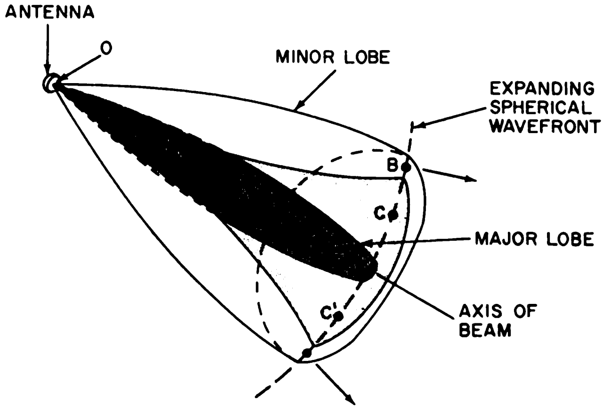

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Figure 8-30.—Radiation pattern from directional antenna.

is normally specified by beam width, which is measured between the half-power level points.

To obtain the greatest accuracy in determining bearing angles, the beam must be as narrow as possible. In figure 8-31, relative signal strength is plotted against angular position of the antenna with respect to the target. The maximum signal is received when the axis of the lobe passes through the target.

BEAM REQUIREMENTS

The tactical application of the radar determines the requirements of the beam. When used for target tracking or missile guidance, operations that require extreme accuracy, the radar beam must be of narrow width, propagated at high frequencies. The narrowness of the antenna beam determines the accuracy with which the radar can measure bearing and elevation. It also determines the angular resolution of the radar, in the same manner as pulse duration determines range resolution. Individual targets adjacent to one another can be detected if the radar set has a narrow beam and sends out a short pulse, as shown in figure 8-32.

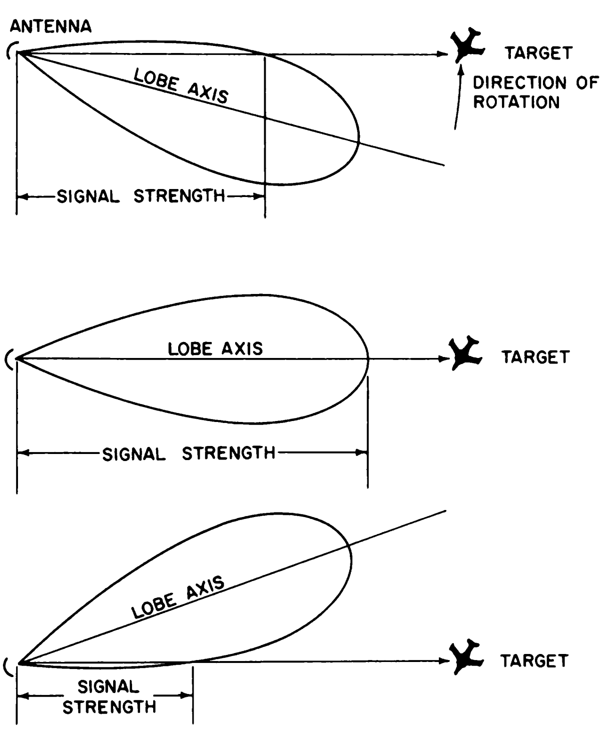

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Figure 8-31.—Relationship between beam axis and target bearing.

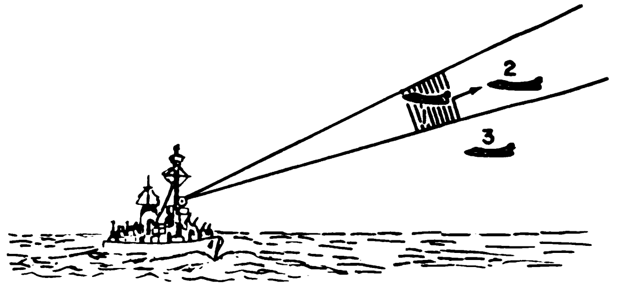

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Figure 8-32.—Radar tracking beam.

BEAM POWER MEASUREMENTS

The relationship of maximum range to beam power characteristics is an important consideration.

The power of a radiated wave, such as a light wave, falls off as the square of the distance between the source and point of measurement. This same law holds here for the field intensity of electromagnetic waves when the power intercepted in a unit area is considered in relation to the distance from the antenna. However, since electric power expressed in terms of the voltage present is proportional to E^2 (because $P = E^2/R$), then the square of the voltage falls off as the square of the distance, or voltage itself falls off as the distance. Target echo strength falls off very rapidly with an increase in range, and a large change in transmitted power will not greatly increase the range of the radar set. If, for example, the peak power is doubled, the range is increased by approximately only 19 percent.

The actual measurement of transmitted power will be discussed in chapter 12.

PRINCIPLES OF REFLECTION, REFRACTION AND DIFFRACTION

The radar transmitter produces the energy and the antenna radiates this energy into space usually in the shape of a narrow beam. The reflection of the short wavelengths utilized by radar takes place from almost all objects in their paths.

Aircraft, missiles, ships, water, or practically any material substance will reflect these short waves. The intensity of the reflected echo depends, among other things, upon the size and shape of that object. From almost any shape some of the reflected energy will be returned to the source, and can be used to identify the target position.

REFLECTION

When a radiated electromagnetic wave encounters a conducting surface, reflection of energy from the surface occurs. Reflection from the surface takes place in accordance with the law of reflection which states that the reflected and incident wave trains travel in directions which make equal angles with the normal to the reflecting surface and are in the same plane with it, figure 8-33. Uneven surfaces reflect in a multitude of directions, and such reflection is said to be diffuse. By far the greatest loss in electromagnetic field intensity which occurs is a result of diffusion.

REFRACTION

Refraction is the bending of a radiated beam as it travels through space. The downward bending of the rays of propagation, shown in figure 8-34, is caused by the non-uniform density of the air at low altitudes, resulting in an increase of refraction.

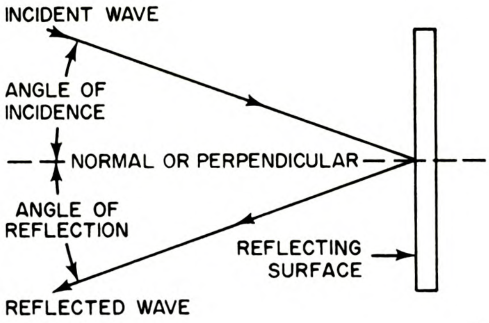

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Figure 8-33.—Reflection.

DIFFRACTION

Diffraction occurs when a wave passes through a restricted aperture (opening or hole) and spreads out in a pattern determined by the ratio of the wavelength to the diameter of the aperture. The importance of this principle in lens or antenna reflecting systems will be explained later in this chapter.

ANTENNAS

The radar energy that forms the target tracking and missile guidance beams is transmitted by an antenna at the control point. Radiated energy

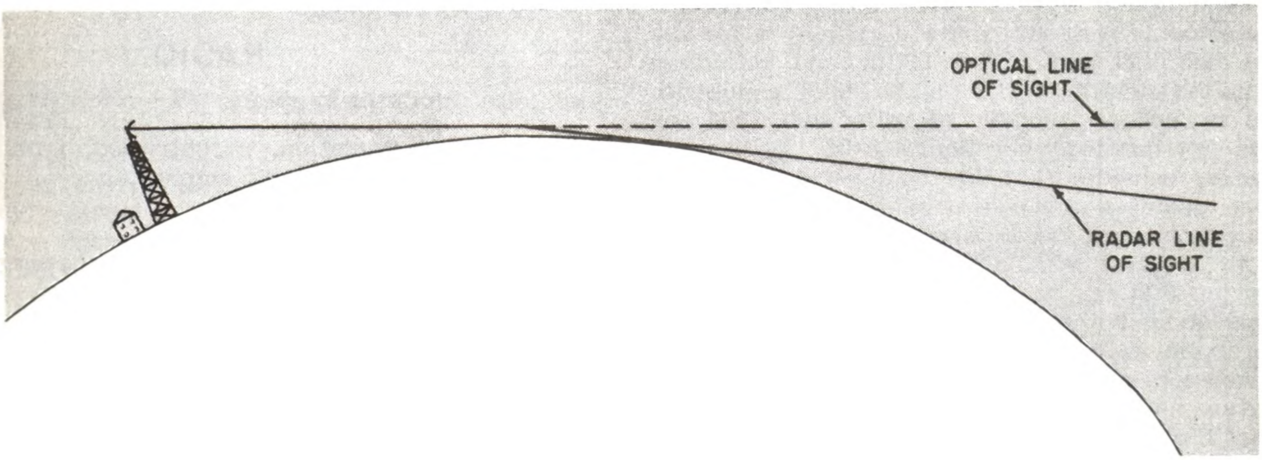

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Figure 8-34.—Extension of radar horizon by atmospheric refraction.

tends to spread out equally in all directions, but by mounting a suitable reflector behind the antenna, a large part of the radiated energy can be formed into a relatively narrow beam.

Figure 8-35 compares the radiation from a radio antenna with that from a lamp. Both light waves and radio waves are electromagnetic radiation; the two are believed to be identical, except in frequency of vibration. From both sources, energy spreads out in the form of spherical waves. Unless they meet some obstruction, these waves will travel outward indefinitely at the speed of light. Because of its much higher frequency, light has a much shorter wavelength than radio waves. This is suggested in figure 8-35, but it cannot be shown accurately to scale. The wavelength of radar transmission may be measured in centimeters; the wavelength of light ranges from about three to seven ten-thousandths of a millimeter.

You are, of course, familiar with the use of polished reflectors to form beams of light. An automobile headlight is an example of this, although it produces a fairly wide beam. A spotlight produces a more narrow beam.

A type of reflector generally employed in missile fire control radars is the parabolic disk. It is similar in appearance to the reflector used in automobile headlights. One of the important advantages of radar operation in the microwave region of the electromagnetic spectrum is that microwaves have properties and characteristics similar to those of light. This permits the use of well known optical design techniques.

The action of the reflecting surface of the reflector is a result of its parabolic shape and the fact that the rays striking and reflecting from the metallic surface make equal angles with the surface at the point of reflection. This action is illustrated in figure 8-36. In A of the figure, consider that the focal point is a feedhorn radiator and is a point source of energy. As you learned, electromagnetic energy is emitted from a point source in spherical waves like ripples that fan out from a pebble thrown into a pond of still water. The primary purpose of the parabolic reflector is to change the spherical wavefronts of the radiated energy into flat (plane) waves and focus them into a circular beam. Part B of figure 8-36 shows spherical wavefronts coming from a radiating feedhorn at the focal point of a parabolic reflector. As the waves strike the reflector they are straightened and concentrated into a narrow circular beam of energy containing parallel flat wavefronts.

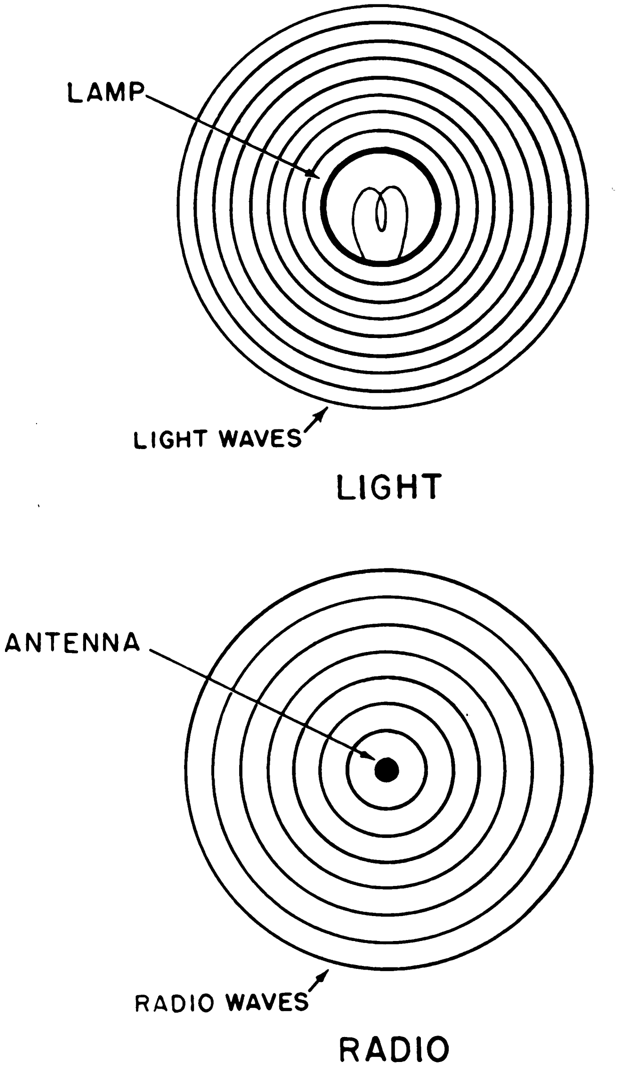

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Figure 8-35.—Radiation, unrestricted, from a lamp and a radio antenna.

When the radar is receiving reflected energy, the incoming rays are concentrated and focused on the feedhorn only when they enter the dish in perfectly parallel rays as shown in B of figure 8-36. The waves reflected from the target, under ideal conditions, will be parallel if they were transmitted in this form. Therefore, we can state that in any antenna system the transmitting and receiving patterns are essentially the same. For this reason one antenna can be used for transmission and reception. The parabolic reflector produces a "pencil beam" in which most

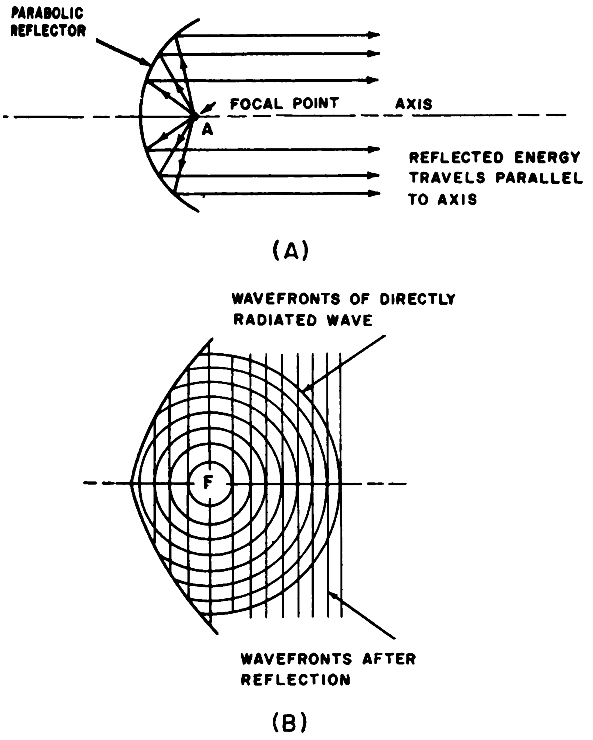
PARABOLIC REFLECTOR
FOCAL POINT
AXIS
A
REFLECTED ENERGY TRAVELS PARALLEL TO AXIS
(A)
WAVEFRONTS OF DIRECTLY RADIATED WAVE
F
WAVEFRONTS AFTER REFLECTION
(B)

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Figure 8-36.—Principles of parabolic reflector.

of the energy is confined to a small cone of nearly circular cross section. The concentration of the energy into a beam increases the amount of radiation illuminating a target.

But no radar can produce an ideal beam of parallel rays. For one thing, the end of the waveguide is large, compared to the ideal point source. For another, a reflector of practical size is not sufficiently large compared with the wavelength of the radiated energy. A radar beam therefore diverges and forms a lobe, like the one in figure 8-37. This is the main lobe or beam. The student should clearly understand that such a lobe is merely a convenient way of representing the beam on paper; it is in no sense a "picture" of the beam. Some of the radiated energy will be scattered outside the main lobe, and will form side lobes, usually of lesser intensity, and much shorter range. They are undesirable lobes that exist in close proximity to the transmitter. And the radiation does not end abruptly at a certain distance from the transmitter, as the diagram implies. The lobe, if it can be pictured in three dimensions, can be thought of as a surface, all parts of which receive an equal amount of energy. This can be considered the minimum energy that is useful for our purpose (missile guidance or target tracking). The lobe in figure 8-37 is not drawn to scale. The diameter of the reflector is in the order of two feet; the length of the lobe may be from 20 to 50 miles. Its useful width may be four or five degrees. At any given distance from the transmitter, the signal is strongest along the axis of the lobe.

In a beam-rider guidance system, radar must accomplish two things; it must track the target, and it must guide the missile. It would be difficult to do either of these things with a simple lobe like the one in figure 8-37.

Target tracking or missile beam riding may be accomplished by nutating the lobe (moving the RF feed point) in a small circle around the focal point of a fixed parabolic reflector. This scanning effect, depicted in figure 8-38, will be studied later in this chapter.

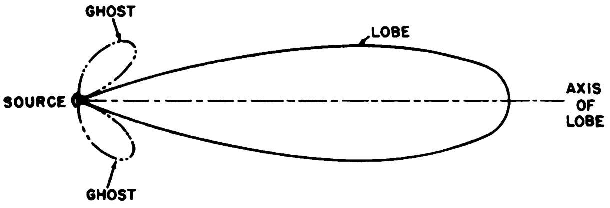

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Figure 8-37.—Lobe formation of radar beam.

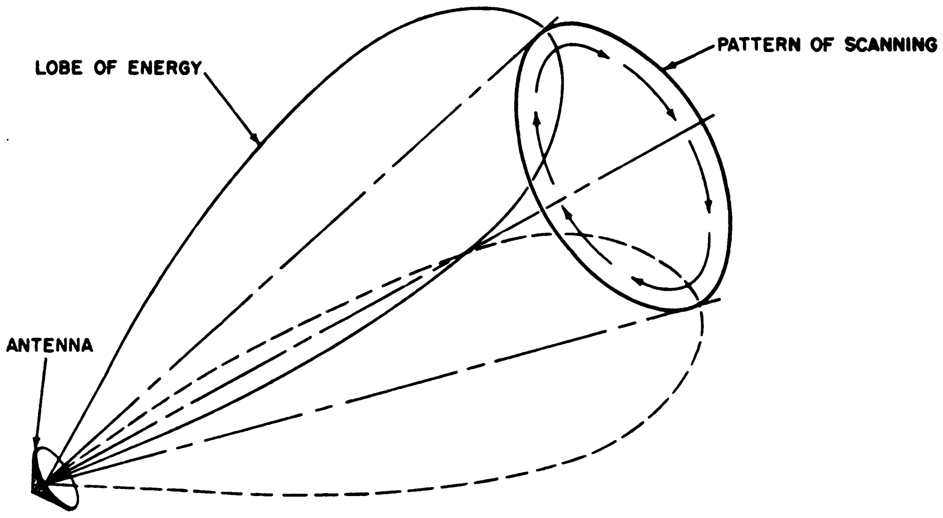

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Figure 8-38.—Nutating lobe.

TYPES OF ANTENNA

Dipole

Although not used by any of the newest modifications of our missiles, several types of missiles have used a rotating dipole antenna. The antenna was not rotated about its center, for this would have changed the polarization as the antenna turned. Such a condition would have caused erratic control of the missile. The antenna is mounted in a plane that passes through the focal point at a right angle to the reflector axis. As the antenna rotates it stays in this plane. The same relative motion can be produced by having a stationary antenna and rotating the reflector about a point off its axis.

Lens Antenna

Lens antennas of two types have been developed to provide a plane wavefront narrow beam for tracking radars, while avoiding the problems associated with feed horn shadow in reflector antennas. (The shadow is a dead spot directly in front of the feedhorn.) These are conducting type and dielectric or delay type. They are also called microwave lenses. The lens is substantially transparent to microwaves but inserts a phase change over the cross section of the exit side of the lens to make the microwaves

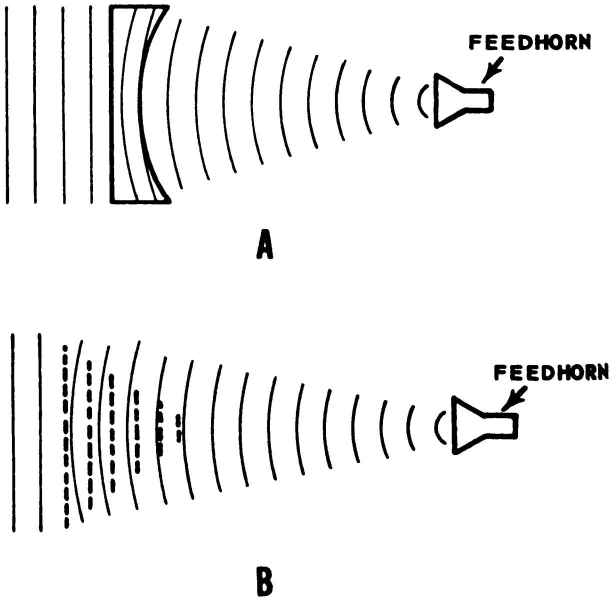

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Figure 8-39.—Antenna lenses: A. Waveguid (acceleration) type microwave lens: B. Metal strip (delay) type microwave lens.

converge or diverge. The lens is placed in front of a point source of RF energy, such as a feedhorn. While a feedhorn is not a "point" source, for analysis of electromagnetic wave propagation it is often considered as a point source of energy.

The conducting type, which is a wave guide, is illustrated in figure 8-39A.

This type accelerates wave transmission as it passes through the lens. It consists of flat metal strips placed parallel to the electric field of the wave and spaced slightly in excess of one-half of a wavelength. To the wave these strips look like waveguides with each hypothetical waveguide having a dimension in a direction perpendicular to the electric field corresponding to the spacing between the parallel strips. The velocity of phase propagation of a wave is greater in a waveguide than in air. Thus, since the lens is concave, the outer portions of the transmitted spherical wave are accelerated for a longer interval of time than the inner portion. The spherical waves will emerge at the exit side of the lens (lens aperture) as flat-fronted parallel waves. The waveguide type lens is frequency sensitive.

The other type lens is the dielectric, or metallic delay lens, shown in figure 8-39B. The delay lens, as its name implies, slows down the phase propagation as the wave passes through the lens. This lens is convex, and consists of dielectric material. The delay in the phase of the wave passing through the lens is determined by the dielectric constant or refractive index of the material. In most cases, artificial dielectrics consisting of conducting rods or spheres that are small compared to the wavelength are used. Artificial dielectrics, or conducting insulators, used in RF transmission systems are covered in Basic Electronics, NavPers 10087-C. In this case the inner portion of the transmitted wave is decelerated for a longer interval of time than the outer portions.

In a lens antenna the exit side of the lens can be regarded as an aperture across which there is a field distribution. This field acts as a source of radiation just as fields across the mouth of a reflector or horn. For a returning echo the reverse effects take place in the lens.

It can be seen that the reflector uses the law of reflection while the lens uses the law of refraction. The rear feed arrangement of the lens antenna eliminates spillover radiation in the backward direction. Also, this arrangement puts the radiator out of the path of the beam, thus reducing shadows.

SCANNING

The systematic movement of a radar beam while searching for or tracking a target is referred to as scanning or lobing. The type and method of scanning used depends on the purpose and type of radar and on the antenna size and design.

TYPES OF SCANNING

A single lobe system is the simplest type of scanning. A stationary lobe cannot satisfactorily track a moving target, let alone provide guidance information to the missile.

Assume that a target is somewhere on the lobe axis, and that the receiver is detecting signals reflected from the target. If these reflected signals decrease in strength, it will be apparent that the target has flown off the axis, and that the beam must be moved to continue tracking. The beam might be moved by an operator who is tracking the target with an optical sight; but such tracking would be slow and inaccurate, and would be limited by conditions of visibility. An automatic tracking system requires that the beam SCAN, or search, the target area.

Again, assume that a missile is riding the axis of a simple beam. The strength of the signals it receives (by means of a radar receiver in the missile) will gradually decrease as its distance from the transmitter increases. If the signal strength decreases suddenly, the missile will know that is is no longer on the axis of the lobe. But it will NOT know which way to turn to get back on the axis. A simple beam does not contain enough information for missile guidance.

The double-lobe system multiplies by several times the accuracy obtainable with a single-lobe system. The double-lobe system employs two overlapping beams. For ease of illustration, assume that two antennas are used side by side. Two signals are obtained when the beams cross a target, one from each beam. On the radarscope they appear either side by side or back to back. The two signals are the same amplitude only when the target is on the line of intersection of the two beams, as in figure 8-40. The operator rotates the antennas until the signals are matched in amplitude. At this point, he knows that the target lies on the LINE OF INTERSECTION of the two beams. The target is located on the basis of returns from the side of each lobe, where a small change in position results in a large change in signal amplitude.

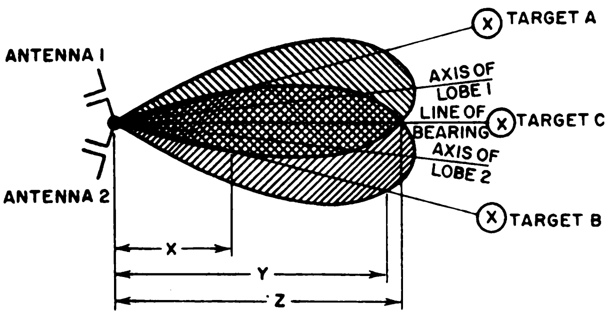

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Figure 8-40.—Double-lobe system, showing relation between axis of intersection and target bearing.

Therefore, if the antennas are moved in either direction away from this angle, one of the signals increases greatly in amplitude and the other decreases. You can see that a greater degree of accuracy can be obtained in this way.

Besides greater accuracy, the double-lobe system has another advantage over the single-lobe system. By watching to see which of the two signals increases in amplitude as the antenna is rotated a few degrees, the operator can tell the direction the antenna must be moved to reach the on-target position.

METHODS OF SCANNING

Two basic methods of accomplishing scanning are mechanical and electronic. In mechanical scanning, the beam can be moved in various ways. The entire antenna can be moved in the desired pattern; the feeder can be moved relative to a fixed reflector; or the reflector can be moved relative to a fixed source. In electronic scanning, the beam is effectively moved by such means as switching between a set of feeder sources, varying the phasing between elements in a multielement array, and comparing the amplitude and phase differences between signals received by a multielement array. A combination of mechanical and electronic scanning is also used in some antenna systems.

MECHANICAL SCANNING

A common form of scanning for target tracking or missile beam rider systems is conical scanning. This is generally accomplished mechanically by nutating the RF feed point.

Nutation

Nutation is difficult to describe in words, but easy to demonstrate. Hold a pencil in two hands; while holding the eraser end as still as possible, swing the point through a circle. This motion of the pencil is nutation. (The pencil point corresponds to the open, or transmitting, end of the waveguide antenna.) The important thing is that polarization of the beam is not changed during the scanning cycle. This means that the axis of the moving feed must not change horizontal or vertical orientation while the feed is moving. You might compare the movement to that of a ferris wheel; the position of the seats must remain the same regardless of the position of the wheel.

Nutating Waveguide

A waveguide is a metal pipe, usually rectangular in cross section, which is used to conduct the RF energy from the transmitter to the antenna. The open end of the waveguide faces the concave side of the reflector, and the RF energy it emits is bounced from the reflector surface.

A conical scan can be generated by nutation of the waveguide. In this process, the axis of the waveguide itself is moved through a small conical pattern. This three-dimensional movement in an actual installation of the waveguide, is fast and of small amplitude. To an observer, the waveguide appears merely to be vibrating slightly.

Nutating Lobe

By movement of either the waveguide or the antenna it is possible to generate a conical scan pattern, as shown in figure 8-41. The axis of the radar lobe is made to sweep out a cone in space; the apex of this cone is, of course, at the radar transmitter antenna or reflector. At any given distance from the antenna, the path of the lobe axis is a circle. Within the useful range of the beam, the inner edge of the lobe at all times overlaps the axis of scan.

Now assume that we use a conically scanned beam for target tracking. If the target is on the scan axis, the strength of the reflected signals will remain constant (or change gradually as the range changes). But if the target is slightly off the axis, the amplitude of the reflected signals will change rapidly and periodically. For example, if the target is ABOVE the scan axis, the reflected signals will be of maximum strength as the lobe sweeps through the highest part of

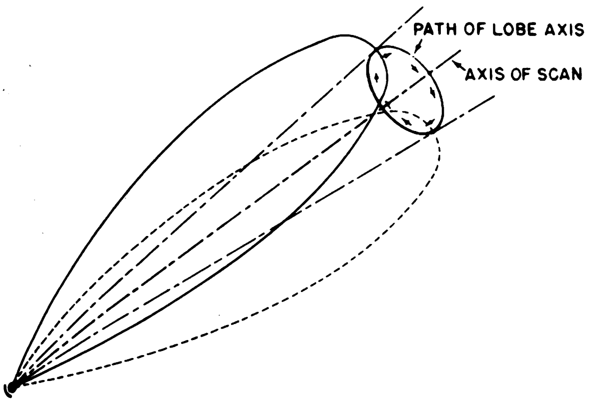

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Figure 8-41.—Nutating lobe, conical scanning.

its cone; they will quickly decrease to a minimum as the lobe sweeps through the lowest part. Information on the instantaneous position of the beam relative to the scan axis, and on the strength of the reflected signals, can be fed to a computer. This computer in the radar may be called angle tracking or angle servocircuit, or angle error detector. If the target moves off the scan axis, the computer will instantly determine the direction and amount of antenna movement required to continue tracking. The computer output can be used to control servomechanisms that move the antenna, so that the target will be tracked accurately and automatically.

When a conically scanned radar beam is used for missile guidance, the desired path of the missile is not along the axis of the beam, but along the axis of the scan.

ELECTRONIC SCANNING

Electronic scanning can accomplish lobe motion more rapidly than, and without the inherent disadvantages of, the mechanical systems. Because electronic scanning cannot generally cover as large a volume in space, however, it is sometimes combined with mechanical scanning in particular applications.

With monopulse or simultaneous lobing, all range, bearing, and elevation angle information of a target is obtained from, as the name implies, a single pulse.

For target tracking, the radar discussed here produces a narrow circular beam of pulsed RF energy at a high pulse repetition rate. Each pulse is divided into four signals which are equal in amplitude and phase. The four signals are radiated at the same time from each of four feed horns grouped in a cluster. The radiated energy is focused into a beam by a microwave lens of the type mentioned previously. Energy reflected from targets is refocused by the lens into the feedhorns. The amount of the total energy received by each horn will vary, depending on the position of the target relative to the beam axis. This is illustrated in figure 8-42 for four targets at different positions with respect to the beam axis. Be sure to notice, and remember, that a phase inversion takes place at the microwave lens similar to the image inversion in an optical system.

The amplitude of returned signals received by each horn is continuously compared with those received in the other horns, and error signals are generated which indicate the relative position of the target with respect to the axis of the beam. Angle servocircuits receive these error signals and correct the position of the radar beam to keep the beam axis on target.

The traverse (train) signal is made up of signals from horns A and C added and from horns B and D added. By waveguide design the sum of B and D is made 180° out of phase with the sum A and C. These two are combined and the traverse signal is the difference of (A + C) - (B + D). Since the horns are positioned as shown in figure 8-43, the relative amplitudes of the horn signals give an indication of the magnitude of the traverse error. The elevation signal consists of the signals from horns C and D added 180° out of phase with A and B, i.e., (A + B) - (C + D). The sum or range signal is composed of signals from all four feedhorns added together in phase. It provides a reference from which target direction from the center of the beam axis is measured. The range signal is also used as a phase reference for the traverse and elevation error signals.

The traverse and elevation error signals are compared in the radar receiver with the range or reference signal. The output of the receiver may be positive or negative pulses, the amplitude of which is proportional to the angle between the beam axis and a line drawn to the target. The polarity of the output pulses indicates whether the target is above or below, to the right or to the left of the beam axis. Of course, if the target is directly on the line of sight, the output of the receiver is zero, and no angle tracking error is produced.

An important advantage of a monopulse tracking radar over one using conical scan is that

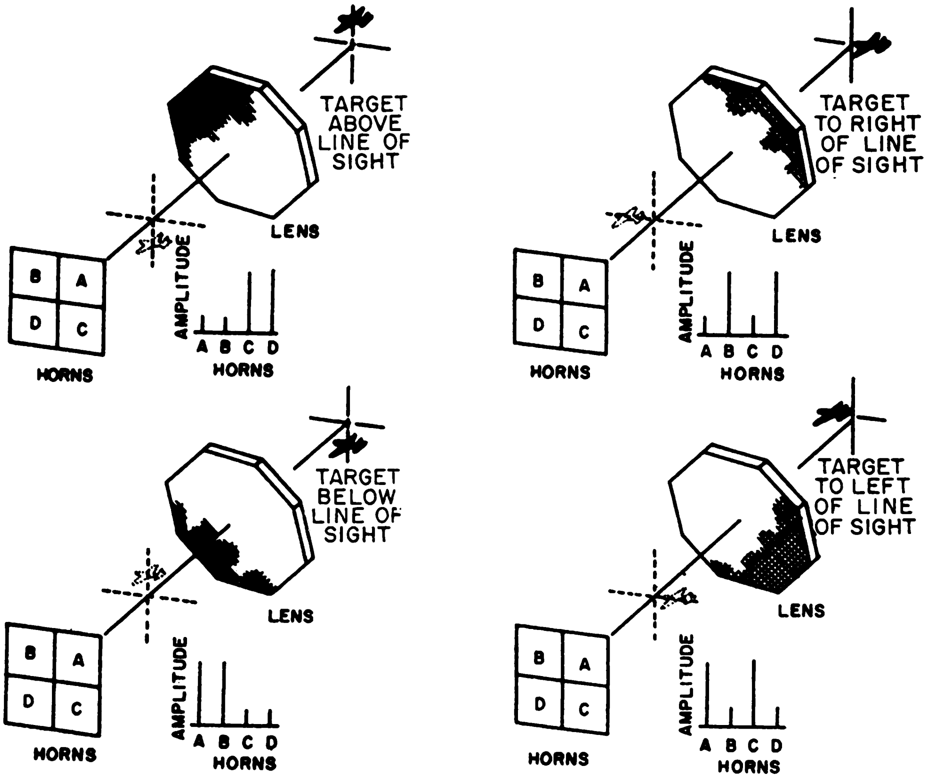

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Figure 8-42.—Monopulse scanning-amplitude changes of received energy with target position.

the instantaneous angular measurements are not subject to errors caused by target scintillation. (As the target maneuvers or moves, the radar beams bounce off different areas of the target and cause random reflectivity which may lead to tracking errors.) A monopulse tracking radar is not subject to this error because each pulse provides an angular measurement without regard to the rest of the pulse train; no cross-section fluctuations can affect the measurement.

An additional advantage of monopulse tracking is that no mechanical action is required, such as a whirling scanner to accommodate while trying to do precise tracking.

DISCRIMINATION AND RESOLUTION

When a target is to be tracked by radar, some difficulty is experienced in separating the target echo from background noise. This difficulty is most severe when a fast target is to be acquired initially by a tracking beam, because the different action between target and echo is limited by the skill of the operator. During the subsequent tracking period, this difficulty remains acute in that the radar beam may not be locked on the desired target. The tracking of a single target is made difficult when there are other targets in the vicinity of the desired target. The ability of a radar to separate a single target from among a number of targets is called its resolving power. A radar set must be able to separate a target in an attacking formation if a missile is to be directed successfully to that particular target. A formation of attacking aircraft composed of one priority target and a number of decoys, for example, may be so constituted and flown that a tracking beam will be unable to fix on one aircraft; instead it will tend to drift from one target to another and will center eventually on a point midway between two targets. The effectiveness of a radar in defeating a countermeasure of this type will be dependent in general on the width of its range gate, relative to the spacing of the aircraft in the formation. Although the complex and variable nature of external noise, which cannot be separated from the internal noise in the receiver, increases the problem of resolution of multiple targets; the utilization of a narrow-band velocity gate, a distinguishing feature of CW-Doppler radars, is effective in eliminating some of this external noise that is present with the target echo.

Range and velocity gating, used singly or together, permit the resolution in range and velocity of targets that are moving in radial paths toward the radar set. The ability of a radar to separate multiple targets which are at the same range but which are separated in angle depends on the optical resolving power of the beam. This factor varies directly with the wavelength and inversely with the effective diameter of the antenna.

A narrow beam is advantageous from the standpoint of noise discrimination, because it is less likely to pick up extraneous noise than a beam of wider angle. However, the improvement in angular resolution is usually at the expense of range capability; hence the advantage of high angular resolution must be compared with the possible disadvantages to the overall performance of the radar or guidance system.

FUNDAMENTAL ELEMENTS OF PULSE RADAR SYSTEMS

Radar systems vary greatly in detail, but the basic features are essentially the same for all pulse radar sets. The functional block diagram shown in figure 8-43 includes the basic components that comprise a pulse radar system. The functional breakdown resolves itself into seven essential components:

(1) The timer — synchronizes the transmitter pulse with the initiation of the time base in the indicator unit

(2) The transmitter — generates RF energy in the form of high-power pulses

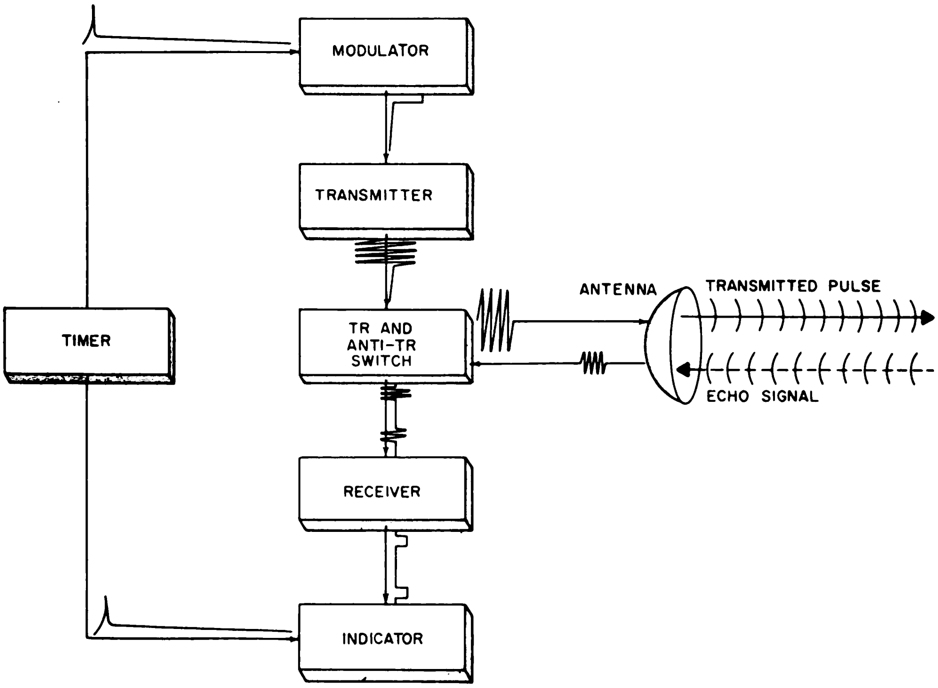

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Figure 8-43.—Basic components of a pulse radar.

(3) The modulator — provides a high-voltage pulse which modulates the transmitter and forms the transmitted pulse.

(4) The antenna system — the antenna has two prime purposes:
1) radiates the RF energy output of the transmitter in a highly directional beam
2) Detects or receives returning echo energy and forwards it to the receiver

(5) The TR and anti-TR switch — Most radar sets employ a single antenna for both transmission and reception. This device assures that the receiver presents a high impedance path to the transmitted energy during periods in which the radar set is transmitting and that this impedance is eliminated during periods in which the set is receiving. It is commonly known as the TR (transmit-receive) switch or as a duplexer, and in certain instances as a polyplexer

(6) The receiver — amplifies and detects echo pulses, and produces amplified output video pulses sent to the indicator

(7) The indicator — provides the visual display of radar information.

THE TIMER

The timer (fig. 8-44) performs the functions of establishing the pulse repetition rate of the radar system and of insuring that the modulator and the indicator operate in a definite time relationship with each other and initiate their functions at the instant that the transmitter produces a pulse of RF energy. Most radars are timed or synchronized by a self-blocking

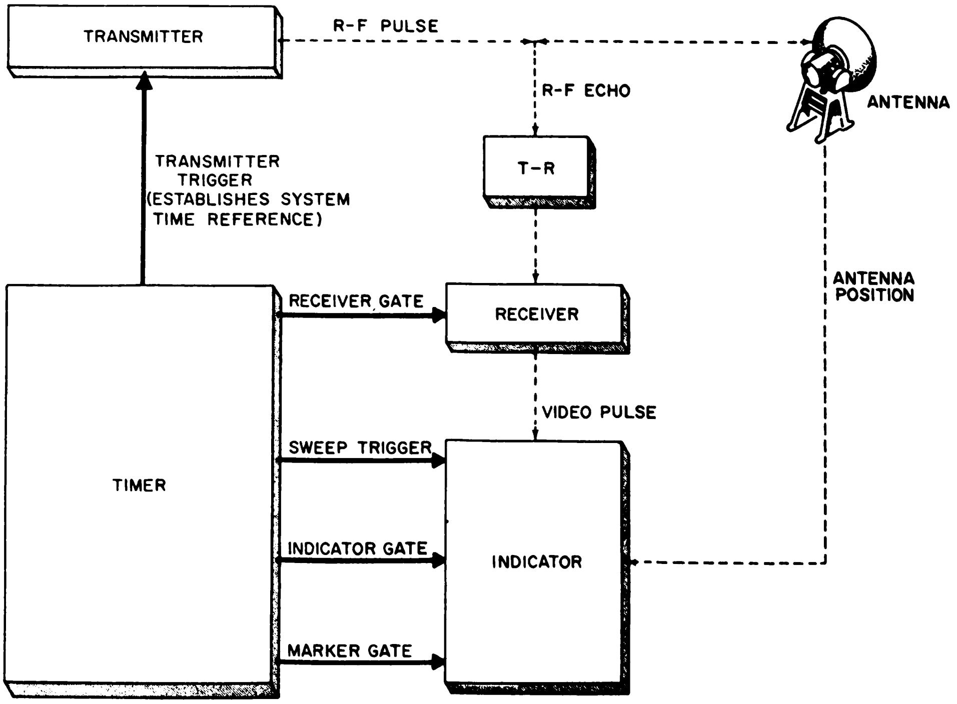

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Figure 8-44.—Timer functions.

oscillator, a sinusoidal oscillator, or a multivibrator, or by the rotary mechanical motion of a spark gap modulator. When oscillators are used to control the repetition frequency, the oscillator output is shaped or sharpened by peaking circuits before being applied as a trigger pulse to the transmitter to synchronize the start of the indicator sweep. The master timing signals may be taken from a ship master oscillator, in which case the radar is said to be externally synchronized, and the master timer in the radar is turned off or bypassed.

As illustrated, in figure 8-45, timing triggers are used for synchronizing and gating, that is for turning circuits on and off at the proper time. The timing triggers, which may be of positive or negative potential, are the output pulses developed in the timer network. The timing triggers that gate the receiver are usually sent through a delay device so that the receiver does not become operative until a short time after the pulse is transmitted, preventing receiver loading during pulse transmission. Timing triggers are used to gate both the indicator and the marker circuits that may be located in the indicator unit. A trigger is used to start the sweep function of the indicator at the proper time.

THE TRANSMITTER

The transmitter (fig. 8-46) functions to generate high-power pulses under the control of the timer. The high-frequency oscillator used in this radar transmitter is a resonant cavity magnetron type. The frequency generated by the

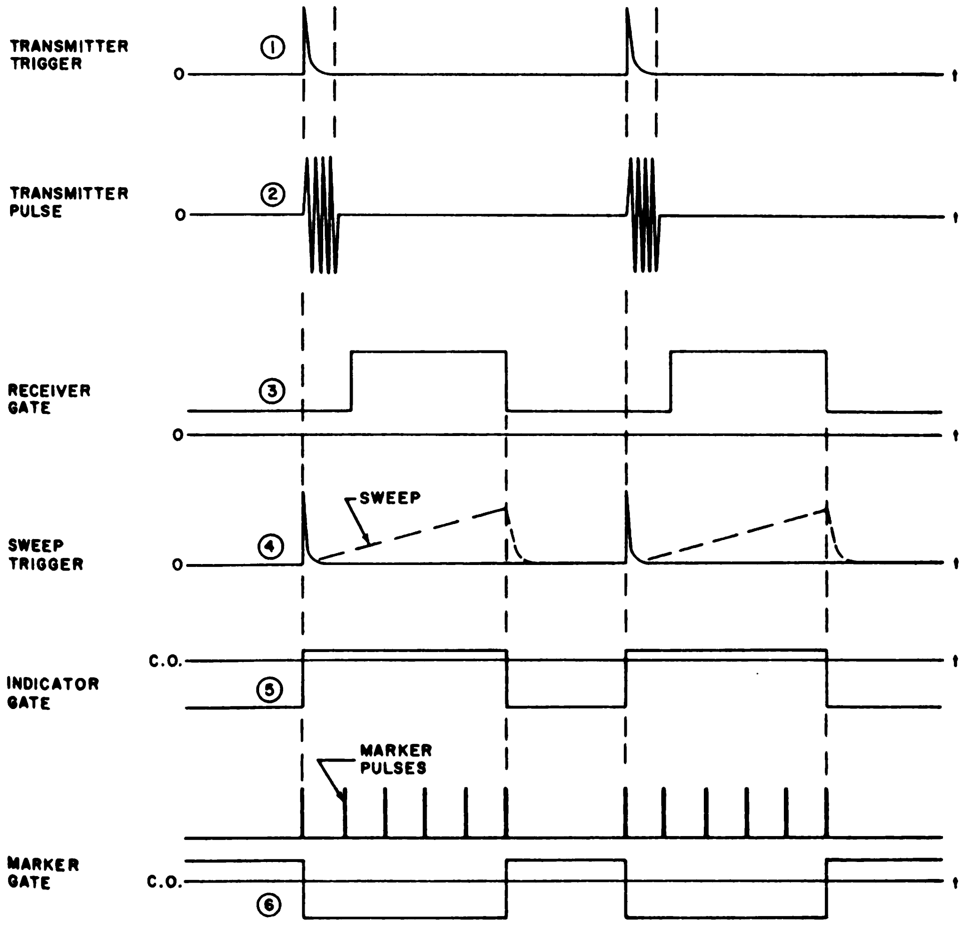

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Figure 8-45.—Use of timing triggers.

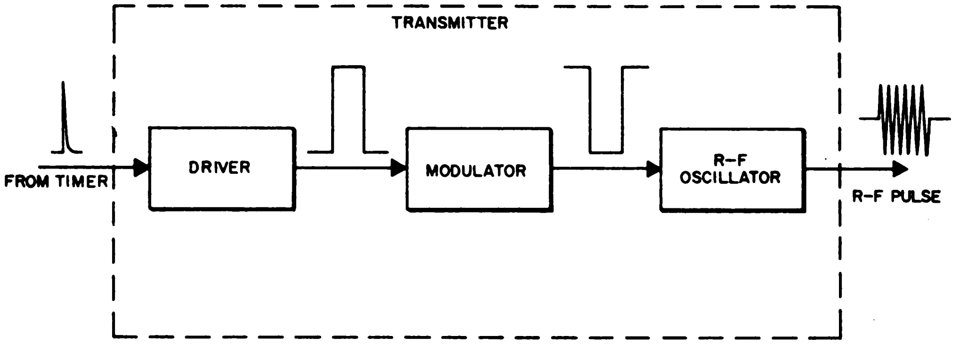

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Figure 8-46.—Externally pulsed transmitter.

magnetron determines the wavelength of the radio waves that are radiated into space. The higher the frequency, the shorter the wavelength. Since short wavelengths can be concentrated into a beam by a relatively small antenna, the wavelengths utilized in military applications are only a few centimeters long, and often of an order of a centimeter or less. In order to produce such short wavelengths, the high-frequency oscillator must generate voltages that alternate at a frequency of several billion cycles per second. The magnetron is well adapted to this high-speed task.

A magnetron consists primarily of a block of copper with resonant cavities inside. The magnetron is usually a diode with a cylindrical anode and an axial, filament-type cathode. A strong magnetic field from an external magnet is directed parallel to the fialment. When a pulse voltage from the modulator excites the cathode, electrons are caused to flow to the anode.

During the electrons travel from cathode to anode the magnetic field causes them to alternately increase and decrease velocity. When the electrons pass the cavities they inpart energy to the cavities to start and sustain oscillations. The cavities are capable of sustaining a definite frequency, called the resonant frequency. The size of the cavity determines the frequency that will be sustained. The smaller the cavity, the higher the frequency. A typical microwave cavity magnetron is shown in figure 8-47. The power output is obtained either by a coupling loop or by a transformer section of a wave guide inserted into a cavity. The loop conveys the power generated inside the magnetron to the wave guide and from there to the antenna to be sent out into space.

Some radars utilize a power amplifier klystron or a traveling wave tube (TWT), described earlier in this chapter, in place of the magnetron.

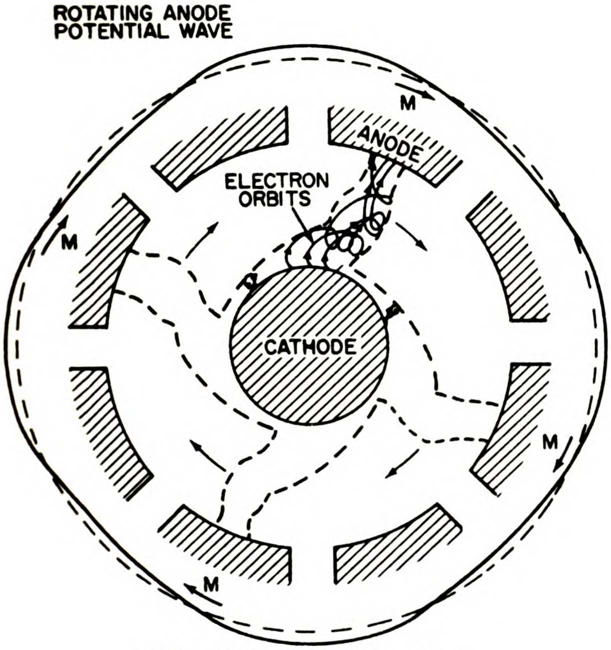
THE MODULATOR

Since the magnetron is a self-excited oscillator, it is necessary for the modulator or pulse generator to modulate the full output of the tube. The term modulator is used to refer to the circuits which control the application of high voltage to the magnetron. Since the expression modulate means to shape as well as to control, the modulator refers to the pulse-forming network as well as to the driver circuitry which produces the pulse that is delivered to the control grid of the modulator stage.

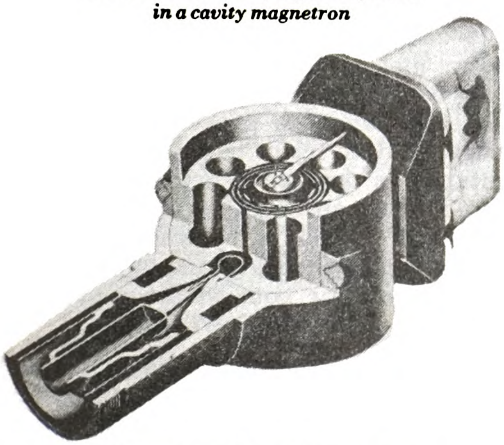
Modulators are also called pulsers or keyers to denote their circuit function. There are two basic types of pulsers, hard-tube and line-type pulsers. The term hard-tube refers to a vacuum tube which controls a capacitor discharge. The pulse is formed in a driver unit and applied to the control grid of the vacuum tube which acts as a switch to control the pulse duration. In line-type pulsers, a lumped-constant transmission line serves as both the energy storage driver and the pulse-shaping element and is called a pulse-forming network (PFN).

The block diagrams of two types of modulator systems are illustrated in figure 8-48. The LINE PULSING MODULATOR (fig. 8-48A) consists of the following components:

1. SOURCE—provides high voltage to the storage element in the modulator.



orbits of electrons of different phases in a cavity magnetron



cut-away view of a cavity magnetron

167.770

Figure 8-47.—The magnetron.

2. Z_{ch}—The total impedance in the storage network charge path.

3. SWITCH—allows the storage network to charge when open; allows the storage network to discharge when closed.

4. PULSE FORMING NETWORK (PFN)—Stores the high voltage provided by the source. Also determines the shape and width of the high voltage pulse applied to the load.

5. LOAD—Primary winding of the pulse transformer.

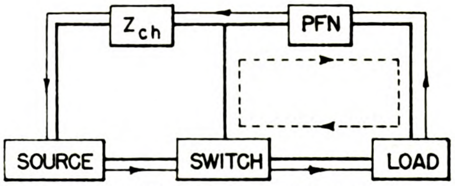
The DRIVER HARD TUBE MODULATOR (fig. 8-48B) differs from the line pulsing type in many respects. (A hard tube is an electron tube which has been evacuated to approach a perfect vacuum as opposed to a tube which contains an appreciable amount of gas (soft tube).) Although the source load (Z_{ch}), the source, and the load are similar to the line pulsing type, the storage network in the hard tube system does not shape the output pulse. The hard tube modulator consists of the following components:

1. Z_{ch} SOURCE LOAD—same as in the line pulsing type.

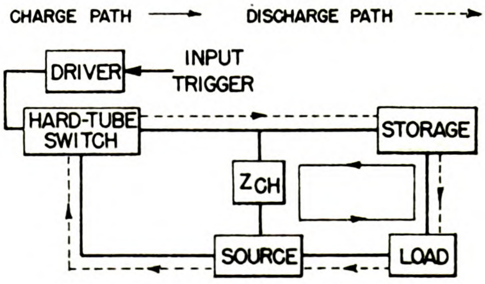
2. STORAGE NETWORK—Usually a large capacitor. (Does not determine pulse width.)

3. HARD TUBE SWITCH—Controls the charge and discharge of the storage unit. When the switch tube is cut off, the storage unit charges; when the switch tube conducts, the storage unit discharges.

4. DRIVER—Input is a trigger from the master timer; output is a HV pulse used to drive the switch tube into conduction. Since the width of this pulse determines how long the switch tube will conduct, the driver pulse width will determine the width of the HV pulse applied to the load.



(A) LINE PULSING MODULATOR



(B) DRIVER HARD-TUBE MODULATOR

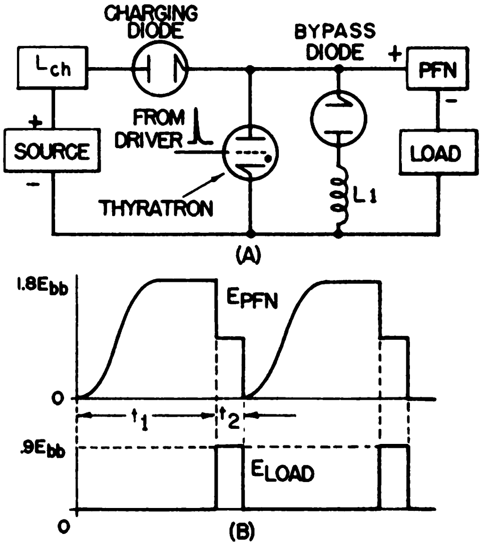
179.660

Figure 8-48.—Two types of modulators.

Whichever type is employed, the modulator furnishes a high-value voltage to the RF oscillator for the predetermined pulsing time, and is responsible for the pulse duration time of the RF oscillator.

After the pulse forming network has been charged, some method of switching must be provided to allow the pulse forming network to discharge through the load. The switch must be able to handle a high pulse repetition frequency and pass a current flow which may exceed 100 amperes. The switch must also provide accurate control of the on and off time interval.

One method of switching is illustrated in figure 8-49A. In this case, a hydrogen thyratron is used as the switching device. During t_1 (fig. 8-49B) the thyratron is not conducting, and the pulse forming network (line) charges through L_{ch} and the charging diode. The pulse forming network charges to approximately 1.8 times the source voltage. At the start of t_2, a trigger pulse, which corresponds in time with the master timer trigger, is applied to the grid of the thyratron. The thyratron is driven into conduction, allowing the line to discharge into the load. Since the line impedance (Z_0) of the line is closely matched to the impedance of the load Z_R, one half of the line voltage is dropped across the load.



179.668

Figure 8-49.—Modulator using a thyratron switch.

At the end of t_2, the line voltage decreases rapidly and the thyratron de-ionizes. The width of the pulse appearing across the load is determined by the two way delay time of the line.

The bypass diode and inductor L are connected in shunt with the thyratron to prevent inverse charging of the line. If an inverse charge is present on the line, the bypass diode conducts providing a discharge path through the inductor. The discharge current produces a magnetic field around L1. When the discharge current stops, the field around L1 collapses causing a slight charge of the proper polarity in the pulse forming network.

Pulse Transformer

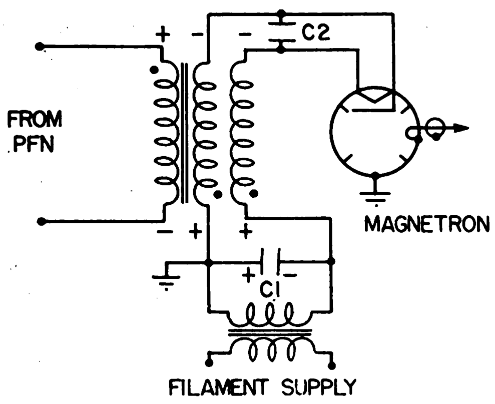
The load connected to the line or storage circuit, will be applied to the pulse transformer of a magnetron (master oscillator power amplifier). A pulse transformer is used to step up the high voltage pulse from the pulse forming network and provide impedance matching between the magnetron and the line. Pulse transformer design is critical because of the high frequency components present in the output pulse. The core is composed of thin laminations of ferromagnetic material, usually silicon steel. Close coupling between primary and secondary reduces leaking inductance to preserve the steep leading edge of the input pulse. Low interwinding capacitance is desired to prevent high frequency oscillations. Close coupling is attained between primary and secondary by winding the primary directly on the secondary and by using the same leg of the core for both windings. The secondary is usually a BIFILAR WINDING.

The bifilar winding secondary is illustrated in figure 8-50. It is made up of two insulated conductors, wound side by side so that exactly the same voltage is induced in each. The bifilar winding acts as two secondaries which have equal and inphase voltages induced in them. The bifilar winding permits the use of a filament secondary without high voltage insulation.

Bypass capacitors, C1 and C2, are often used so that pulse current will flow directly to the bifilar winding, without affecting the filament circuit.

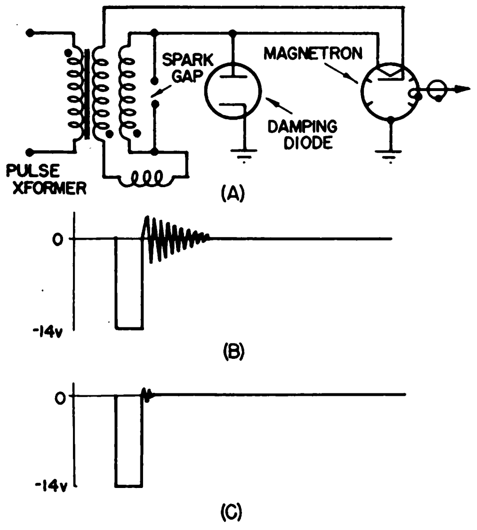
Protective Devices

Occasionally, an OVERVOLTAGE condition may exist in the pulse forming network. The



179.669
Figure 8-50.—Bifilar secondary.

line will charge to a higher voltage than normal, and an excessively high negative pulse will be applied to the magnetron. Frequent overvoltages can cause arcing and damage to the magnetron. An overvoltage spark gap is connected across the pulse transformer secondary to prevent excessively high pulse voltages from being applied to the magnetron (fig. 8-51). The gap width is manually adjusted for the desired value of voltage which will produce arcover.



179.670
Figure 8-51.—Protective devices used with the magnetron.

Stray capacitance and leakage inductance in the pulse transformer secondary circuit, produce a series of oscillations after the main pulse has been applied (fig. 8-51B). The negative portions of this waveshape will produce a spurious output from the magnetron which can obliterate any short range targets. These oscillations are not produced during the main pulse, due to the low impedance shunting provided by the conducting magnetron. A DAMPING DIODE is connected in parallel with the magnetron to eliminate the effects of these oscillations. When the negative main pulse is applied to the magnetron cathode, the damping diode does not conduct. The damping diode will conduct during the positive portion of the oscillations (fig. 8-51C); shunting the magnetron with a low impedance and causing the oscillations to dampen very rapidly.

THE ANTENNA SYSTEM

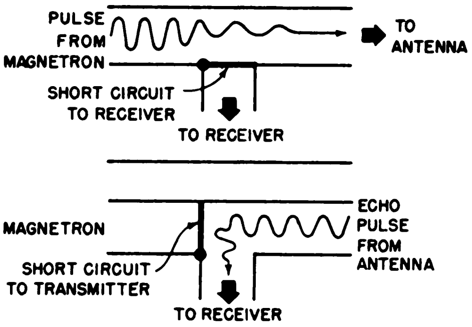
As you have already learned, the antenna system consists of a reflector or lens for beaming the radiated energy; and for conical scanning radars, a motor for nutating the feedhorn.

The servo positioning units which position the antenna (fire control director) in train and elevation are not always a physical part of the antenna, but are connected to the fire control director and will be explained in the next chapter.

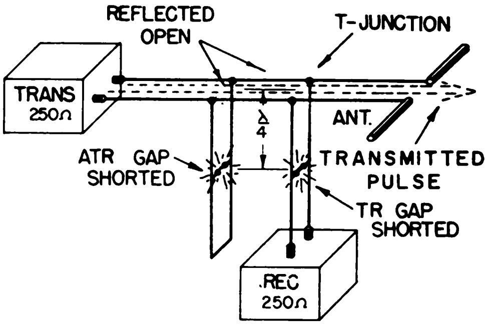
TR AND ANTI-TR DEVICES

In a radar set, the transmit-receive switch is a part of the transmission line structure. Whenever a single antenna is used for both transmitting and receiving, some means must be provided to keep the high power output of the transmitter from entering the receiver circuitry during the transmit portion of the cycle and to provide a path to the receiver for the echo signal during the receive portion of the cycle, while preventing an energy loss to the transmitter. The TR device performs the first of these functions, and the anti-TR device performs the second. As a result of the high frequencies employed, no mechanical switching arrangements are available which can effectively operate within microsecond limitations.

The simplest and most basic device that can be substituted for a mechanical switch is a spark gap because it acts as an open circuit (infinite impedance) until sufficient voltage is applied to cause arcing, at which time it has



167.771
Figure 8-52.—TR and ATR principles.



179.749
Figure 8-54.—Parallel connected duplexer system during transmission.

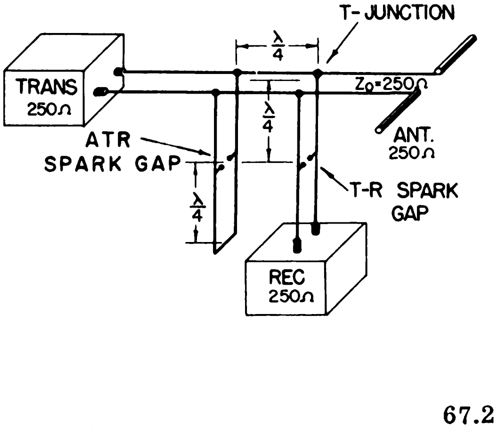
the characteristics of a short circuit (zero impedance), figure 8-52.

In order to analyze the overall action of the TR-ATR circuits, recall that a quarter-wavelength section of transmission line (or odd multiple thereof) inverts the impedance from end to end. (Wavelength impedances are discussed in Basic Electronics, NAVPERS 10087-C.) The TR spark gap in figure 8-53 is located in the receiver coupling line one-quarter wavelength from the tee (T) junction. A quarter-wavelength from the T junction (in the direction of the transmitter) a half-wavelength, closed-end section of transmission line, called a STUB, is shunted across the main transmission line. An ATR spark gap is located in this line one-quarter wavelength from the main transmission line, and one-quarter wavelength from the closed end of the stub. As shown in figure 8-53, the antenna impedance, the line impedance, and the transmitter output impedance when transmitting are all equal.

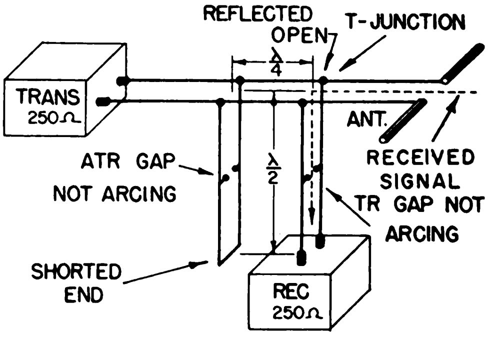
During the transmitting pulse, an arc appears across both spark gaps and causes the TR and ATR circuits to act as a shorted (closed-end) quarter-wave stub and reflect an open circuit to the TR and ATR circuit connections to the main transmission line (fig. 8-54).

None of the transmitted energy can pass through these reflected opens into the ATR stub or into the receiver. Therefore, all of the transmitted pulses is directed to the antenna.

During reception, the amplitude of the received echo is not sufficient to cause an arc across either spark gap (fig. 8-55). Under this condition, the ATR circuit now acts as a half-wave transmission line terminated in a short-circuit. This is reflected as an open circuit at the receiver T junction,



67.20(179)
Figure 8-53.—Parallel connected duplexer system showing distance and impedance.



179.750
Figure 8-55.—Parallel connected duplexer system during reception.

three-quarter wavelengths away. The received echo sees an open circuit in the direction of the transmitter. However, the receiver input impedance is matched to the transmission line impedance so that the entire received signal will go to the receiver with a minimum amount of loss.

Standing Wave Ratio

A standing wave is a distribution of current and voltage in a waveguide formed by two sets of waves traveling in opposite directions, caused by reflections within the waveguide. Improper waveguide coupling between RF lines and the antenna or transmitter, for instance, may produce an impedance mismatch resulting in a high standing wave ratio, magnetron or klystron instability, and a general reduction in system performance.

The antenna system, to efficiently transfer RF energy, should have a low standing wave ratio (SWR). Two devices, couplers and slotted line sections, are used to provide points at which this ratio measurement may be made. Couplers and slotted lines may be either built into the system or come separately as test equipment.

A low standing wave ratio is maintained principally for the following reasons: Reflections occurring in the RF line cause magnetron pulling and may result in faulty pulsing; arc-over may occur in the RF line at maximum voltage points; mechanical breakdown in the line sometimes may occur, due to the development of hot spots.

RECEIVERS

The RF echo pulses reflected by a distant object are similar to the transmitted pulses discussed previously, but are considerably diminished in amplitude. These minute signals are amplified and converted into video pulses by the receiver. A voltage amplification in the order of 10^{10} is required to produce a video pulse of sufficient amplitude to intensify the beam of a crt. The receiver must accomplish this amplification with minimum introduction of noise voltages.

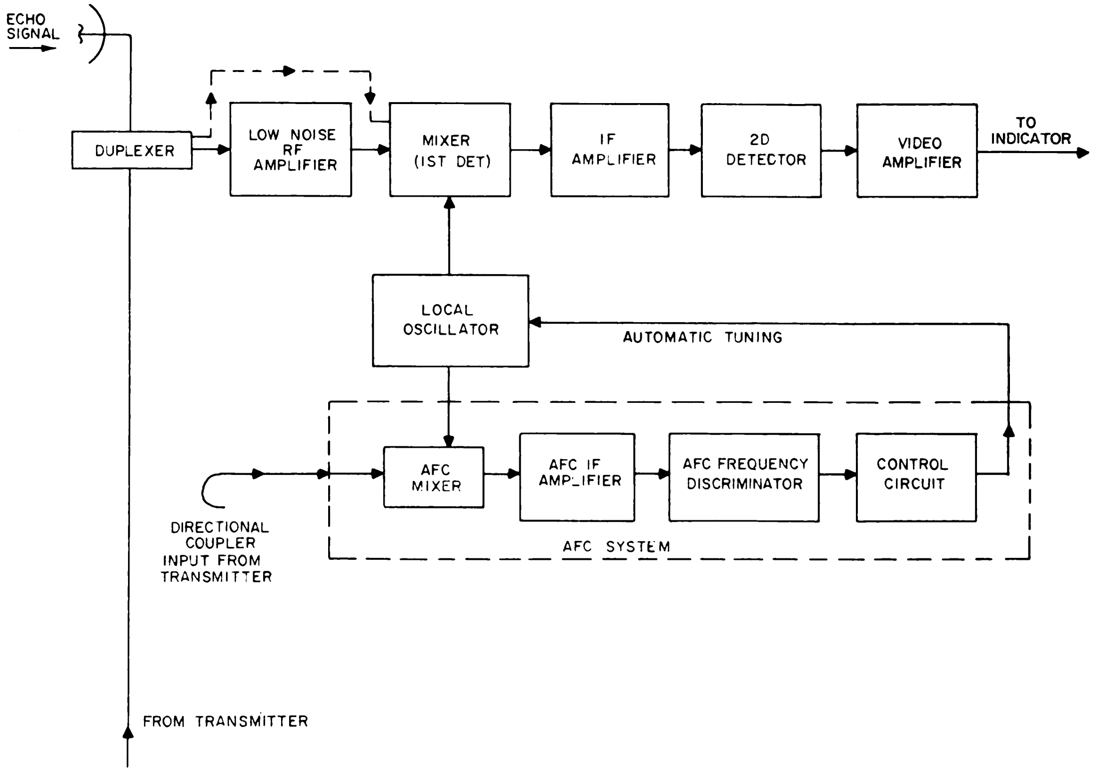
The superheterodyne receiver is exclusively used in microwave systems. A simple block diagram of a microwave receiver based on the superheterodyne principle is shown in figure 8-56. The echo signal enters the system via the antenna shown in the upper left-hand corner of figure 8-56. It passes through the duplexer (TR and anti-TR) and is amplified by the low-noise RF amplifier. (TWT's, parametric amplifiers, and masers are representative devices which are used as low noise, high gain RF amplifiers.) When external noise is negligible, the noise generated by the input stage of the receiver largely determines the receiver sensitivity. In early radar receivers and some present day receivers, an RF amplifier is not used and the mixer is the first stage (as indicated by the dashed path in fig. 8-56). The function of the mixer stage, or first detector, is to translate the RF to a lower intermediate frequency, usually 30 or 60 MHz. This is accomplished by heterodyning the returning RF signal echo with a local oscillator signal in a nonlinear device (mixer) and extracting the signal component at the difference frequency (IF). The purpose of this process is that by using the intermediate frequency, the necessary gain is easier to obtain than by using the higher RF. It is also easier to develop the response function (or bandpass characteristic) of the receiver IF stages. The second detector, which is sometimes an electron tube but more often a crystal rectifier, extracts the video modulation from the carrier. The modulation is amplified in the video stages to a level high enough to operate the indicator or display devices.

Automatic Frequency Control (AFC)

The AFC system (fig. 8-56) normally employed to keep the receiver in tune with the transmitter is known as a DIFFERENCE-FREQUENCY SYSTEM. In this system a portion of the transmitter signal is coupled into the AFC mixer and is heterodyned with the local oscillator signal. If the transmitter and receiver are correctly in tune, the resultant difference frequency will be at the correct IF. If the receiver is not in tune with the transmitter, the difference frequency will not be correct. Any deviation from the correct IF signal is detected by the AFC frequency discriminator, which in turn, generates an error voltage which magnitude is proportional to the deviation from the correct IF, and which polarity determines the direction of the error. The error voltage corrects the frequency of the local oscillator common to both the receiver mixer and AFC mixer.

Local Oscillator

In radar, most receivers use 30- or 60-MHz intermediate frequencies. A highly important factor in receiver operation is the tracking stability of the local oscillator which generates



179.7

Figure 8-56.—Microwave receiver based on the superheterodyne principle.

the frequency that beats with the incoming signal to produce the IF. For example, if the local oscillator frequency is 3000 MHz, a frequency shift of as much as 0.1% would be a 3-MHz frequency shift. This is equal to the bandwidth of most receivers and would cause a considerable loss in gain.

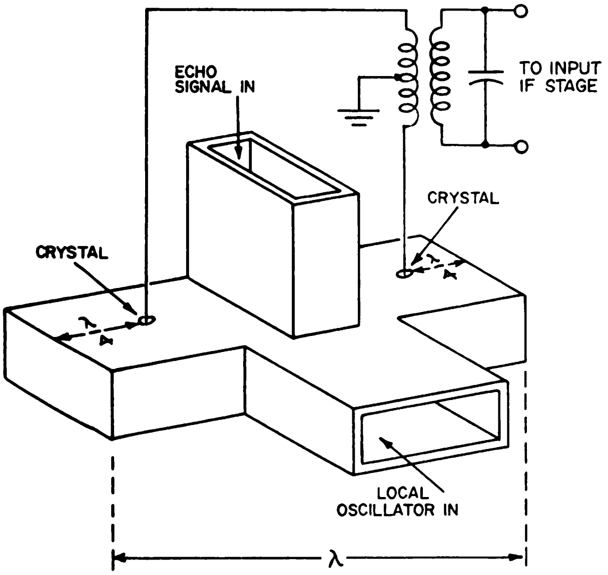
In receivers which use crystal mixers, the power required of the local oscillator is small, being only 20 to 50 milliwatts in the 4000-MHz region. Due to the very loose coupling, only about one milliwatt actually reaches the crystal.

Another requirement of a local oscillator is that it must be tunable over a range of several megahertz. This is to compensate for changes in the transmitted frequencies and in its own frequency. It is desirable that the local oscillator have the capability of being tuned by varying the voltage applied to it.

Because the reflex klystron meets the above requirements, it is used as a local oscillator in microwave receivers.

Balanced Mixer

One type of mixer which cancels local os lator noise is the BALANCED, or HYB MIXER (sometimes called the MAGIC TE Figure 8-57 illustrates this type of mixer. hybrid mixers, crystals are inserted direc into the waveguide. The crystals are located o quarter wavelength from their respective sho circuited waveguide ends. This is a poin maximum voltage along a tuned line. The crys are also connected to a balanced transformer secondary of which is tuned to the desired The local oscillator signal is introduced into waveguide local oscillator arm and distrib itself as shown in figure 8-58A. Observe that LO signal is the same phase for each crys The echo signal is introduced into the echo sig arm of the waveguide and is of different pha for each crystal, as illlustrated in figure 8- The resulting fields are illustrated in fig 8-58C.



67.31
Figure 8-57.—Balanced hybrid crystal mixer.

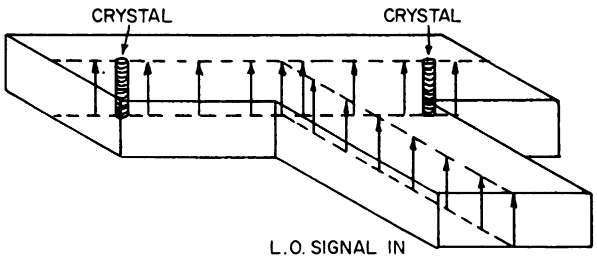
Since there is a difference in phase between echo signals applied across the two crystals, and because the signal applied to the crystals from the LO is in phase, there will be a condition when both signals applied to crystal #1 will be in phase, and the signals applied to crystal #2 will be out of phase. This means that an IF signal of one polarity will be produced across crystal #1 and an IF signal of the opposite polarity will be produced across crystal #2. When these two signals are applied to the balanced output transformer (fig. 8-57) they will add. Outputs of the same polarity will cancel across the balanced transformer.

It is this action which eliminates the LO noise. Noise components which are introduced from the LO are in phase across the crystals and are therefore cancelled in the balanced transformer. It is necessary that the RF admittances of the crystals be nearly equal or the LO noise will not completely cancel. It should be noted that only the noise produced by the LO is cancelled. Noise arriving with the echo signal is not affected.

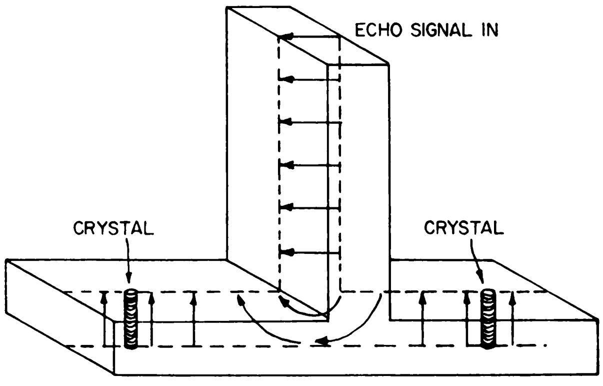
IF Amplifiers

The IF section of a microwave receiver determines the receivers gain, signal-to-noise ratio, and effective bandwidth. The IF amplifier stages must have sufficient gain and dynamic range to accommodate the expected variation of echo signal power. They must have a low noise figure and a bandpass wide enough to accommodate the range of frequencies associated with the echo pulse.

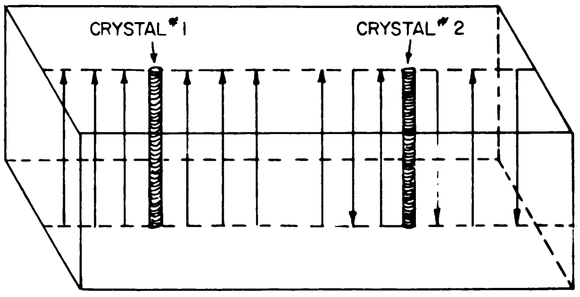
The most critical stage of a microwave receiver's IF section is the input or first stage. Upon the excellence of this stage, depends the noise figure of the receiver and the performance of the entire receiving system with respect to detection of small objects at long ranges. Not only must gain and bandwidth be considered in



A.WAVEFORM AND LOCAL OSCILLATOR ARM



B.WAVEGUIDE AND ECHO SIGNAL ARM



C. WAVEGUIDE

179.740
Figure 8-58.—Balanced mixer fields.

the design of the first IF stage, but also, and perhaps of more importance, noise generation in this stage must be low. Noise generated in the input IF stage will be amplified by succeeding stages and may exceed the echo signal in strength.

IF stages succeeding the first stage may use pentodes to achieve higher gain. This is possible because the signal level has been sufficiently increased by the low noise input stage so as to preclude problems caused by noise generation of pentodes.

The gain of an IF amplifier is high. Because of this high gain, caution must be used to prevent the least amount of regenerative feedback. A small value of voltage in the proper phase fed back to a previous IF stage will cause the amplifier to break into oscillations. Because of this, great care is taken to minimize the possibility of positive feedback. Extensive decoupling in the plate and heater circuits of microwave IF amplifiers is necessary and generally provided. IF amplifiers in microwave receivers are usually isolated and well shielded to prevent any undesired feedback or coupling.

The tuning of an IF amplifier section is generally critical. Whenever required, it should be done in accordance with the instructions contained in the manual for the particular equipment concerned, and care should be excercised.

Video Detector and Amplifier

The output of the IF stage is converted to video-frequency signals by the detector stage, which is usually a diode. There is normally a slight loss of amplification in this stage. The video amplifier is used to amplify the detected pulse voltage to the required magnitude necessary to operate the indicator. A cathode follower is used to couple the video signal output to the indicator. A characteristic of a cathode follower is its impedance-matching ability. It is necessary to match the output impedance of the video amplifier to the input admittance of the scope, to minimize the noise, distortions and attenuations that would normally occur when a coaxial cable is used to feed signals through to a remotely located indicator.

Receiver Sensitivity

Increasing the sensitivity of the receiver also increases the maximum range of the radar set. The more sensitive the receiver, the longer the maximum range at which an echo signal can be detected. The ability of the receiver to detect and amplify a minute quantity of energy is a mark of the quality of the receiver and the factor which determines the maximum range of the radar set.

The method of measuring receiver sensitivity will be examined in chapter 12.

DISPLAY OF INFORMATION

After the video pulse has been amplified, it must be supplied to the indicator. An indicator produces a visual indication of the echo pulses in a manner designed to furnish required information content. The parameters desired are range, bearing, and elevation of targets. The indicator may be some distance from the radar receiver. The output of video amplifiers must be transmitted, by coaxial cable, to the indicator. To accomplish this with a maximum transfer of power requires that the output impedance of the video amplifier be matched to the impedance of the coaxial cable. As the characteristic impedance of coaxial cable is relatively low, a cathode follower is used to accomplish the impedance match.

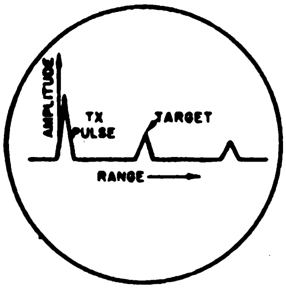
If the video signal must be transmitted a considerable distance, there may be a significant cable attenuation loss. To overcome such line losses, indicators contain additional video amplifiers.

Types of Radar Scopes

The type-A presentation (fig. 8-59A) is used to determine range. The screen of this scope has a short persistence. The echo causes a vertical displacement of the electron beam, the amplitude of which depends on the strength of the returned signal pulse. The point on the horizontal base line at which the vertical displacement occurs indicates the range.

The E scan (fig. 8-59B) presentation is another type of scan for presenting range and height information. The E scan is also known as the RHI (Range Height Indicator) scan. In the type E scan an echo appears as a bright spot with range indicated by the horizontal coordinate and the elevation (height) as the vertical coordinate. This type is used in Weapons Direction Equipment (WDE) and Weapons Control Stations (WCS).

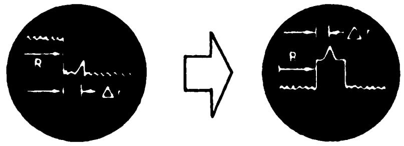
The PPI (Plan Position Indicator) presentation (fig. 8-59C) is the most common type of scan for range and bearing information. It utilizes an intensity-modulated system with a linear radial sweep for range, and a circular sweep (synchronized with antenna bearing) for target bearing.



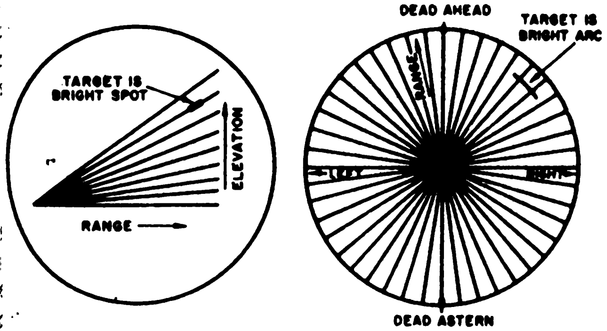
A. TYPE A SCAN

M (movable pedestal for accurate ranging)

R (expanded linear sweep for accurate ranging)



TYPE A SCAN MODIFIED



B. TYPE E SCAN

C. TYPE P (PPI)

20.281

Figure 8-59.—Radar indicators.

CW RADAR SYSTEMS

The basic components of a CW Doppler type radar are a TRANSMITTER (oscillator), MODULATOR, ANTENNA, RECEIVER and INDICATOR. Basically, circuit operation of a CW radar is similar to that of a pulse radar.

FUNDAMENTAL DOPPLER SYSTEM

A block diagram of a basic Doppler radar is illustrated in figure 8-60. The transmitter output frequency of 3000 mHz (10 cm) is modulated with the second harmonic output of a 15-mHz oscillator. The 3030-mHz modulated signal is fed into the crystal mixer stage. The crystal mixer heterodynes the 3030-mHz signal with the received signal. The frequency of the received signal is now 3000 mHz plus or minus an audio Doppler shift frequency caused by a motion of the target. The resultant frequency is fed to the IF amplifier. The frequency modulator of the tranamitter assures a constant intermediate frequency and avoids tuning problems. The IF amplifier stage, a predetermined high-voltage gain stage, is tuned to a narrow IF bandwidth. The output of this stage is fed to the second detector. The second detector stage utilizes a 30-mHz crystal oscillator to beat against the output of the IF amplifier, producing the audio Doppler-shift frequency. The audio frequency is then amplified in the audio amplifier and applied to the indicator. The system as described does not indicate the magnitude of the radial velocity and is a basic simple Doppler Radar system used to indicate changes in velocity.

COMBINATION SYSTEMS

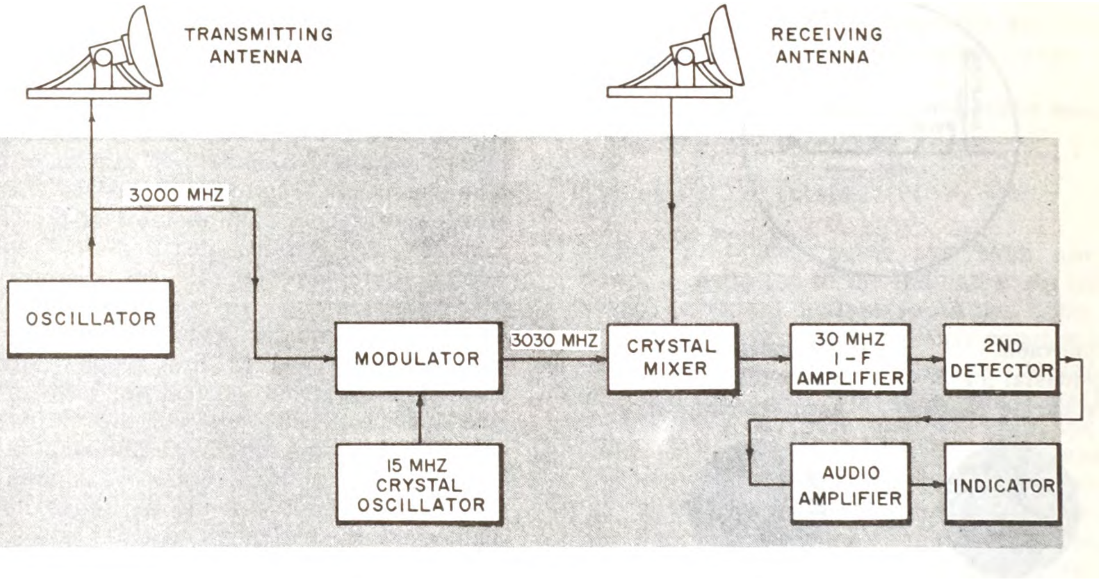
The previously described CW Doppler radar can distinguish between fixed and moving targets and measure velocity, but cannot measure range.

Pulse radars can measure range, but they cannot reject clutter echoes from fixed targets. A combination of the two can be used to measure the range and the velocity of a moving target.

Such a combination radar set may be designed either as a pulse-modulated Doppler radar or as a moving target indicator (MTI) radar. If the pulse length is more than 10 percent of the wavelength, the radar set is classified as a CW pulse-modulated Doppler system; if the pulse length is less than 10 percent of the wavelength, the set is classified as an MTI system. The shorter pulse length of MTI radars gives them greater resolution and permits them to handle more targets simultaneously. However, the longer pulse length of pulse-modulated Doppler radar permits more efficient recovery of Doppler frequencies and better rejection of clutter echoes from stationary targets.

Pulse-Modulated Doppler System

The block diagram of a pulse-modulated Doppler system is shown in figure 8-61. Since pulses are used, only one antenna is needed. The square-wave generator, modulator, and TR and ATR



167.772

Figure 8-60.—Basic Doppler radar system, block diagram.

tubes control the keying cycle, as in any pulse radar.

The video pulse-echo waveforms, figure 8-62, are shown. The Doppler frequency appears as the envelope frequency of the waveform. The change in phase from pulse to pulse is caused by the motion of the target. The distance traveled by the target between pulses is vT, where v = velocity of target and T = time between pulses. Therefore, each pulse travels a distance of $2vT$ (or $2vT/\lambda$ wavelengths) less than the preceding pulse. This is equivalent to a phase change of $2(2vT/\lambda)$ between pulses, or to the Doppler frequency.

The echo waveform can be explained also in terms of frequency components. A pulsed carrier consists of a carrier frequency plus the components due to the pulse waveform. A rectangular pulse repeated at a frequency f_r has components of f_r, $2f_r$, $3f_r$,. . .and so forth, that is, nf_r, where n = any integer. If the pulsed carrier is heterodyned to zero frequency, the carrier frequency is translated to zero frequency. However, any other components do not disappear, and the output consists of the video components, nf_r, plus whatever Doppler is imposed on the signal by target motion.

Echoes from stationary targets, as illustrated, have components of nf_r after the carrier has been removed. The echoes from a moving target have a Doppler-frequency (f_d) added to the square-wave frequencies (nf_r). Just as any amplitude-modulated wave is the vector sum of a carrier and one or more sidebands, the sum of nf_r and f_d is a succession of pulses (nf_r) which are amplitude modulated at the Doppler frequency (f_d). The rejection of clutter echoes and the recovery of range information from the Doppler frequency is based on the fact that the echoes from moving targets have frequency components $nf_r + f_d$, whereas echoes from fixed targets have nf_r components.

Each echo is heterodyned first to 30 mHz, and then to zero frequency, as in the simple Doppler system. The envelope of the output of mixer 3 thus contains only frequencies of nf_r (from the pulses) and f_d (from Doppler effect), so that the echoes from stationary targets are as shown in curve (A), and those from moving targets as in curve (B), in figure 8-62.

The signals from stationary objects are rejected in the clutter filter which follows mixer 3. The clutter filter is a series of narrow band cut-off or infinite attenuation filters that reject frequencies of f_r, $2f_r$, $3f_r$, . . . and so forth.

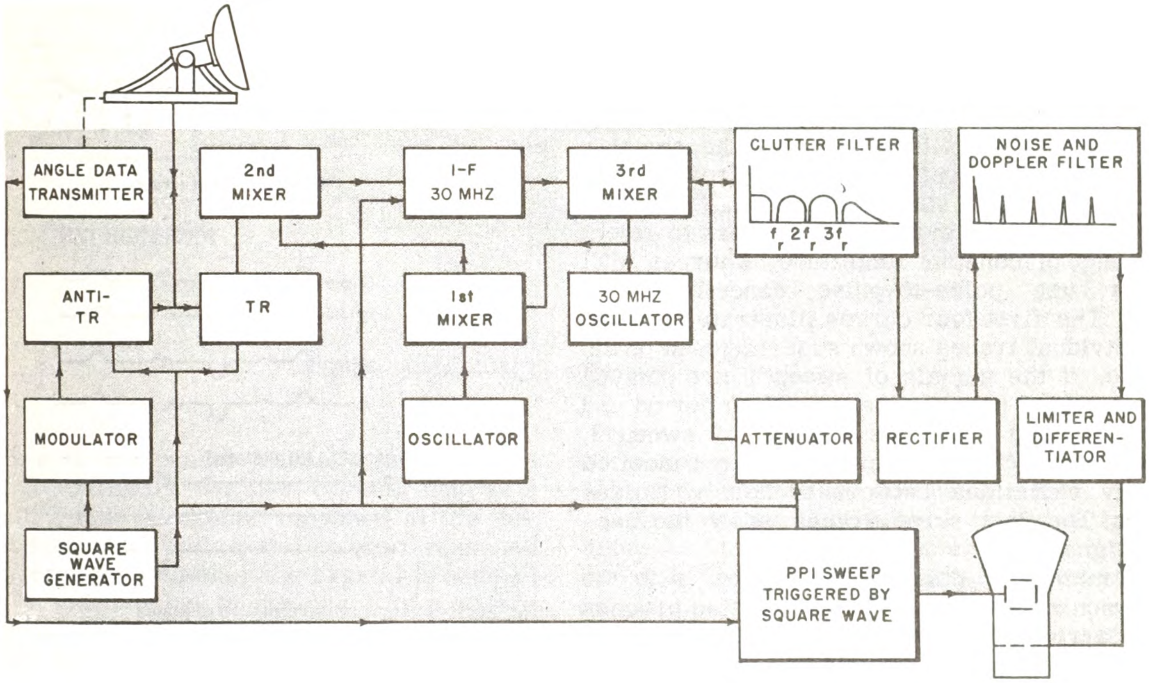


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Figure 8-61.—Pulse-modulated Doppler system, block diagram.

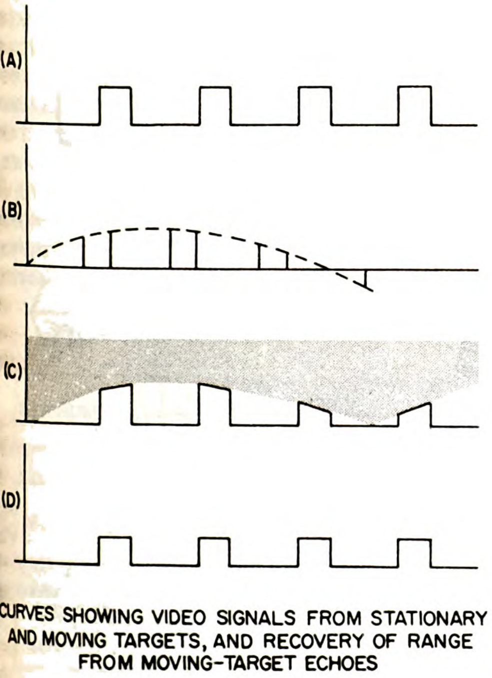

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Figure 8-62.—Curves showing video signals from stationary and moving targets.

The output of the clutter filter thus consists only of Doppler-frequency pulses, that is, pulses whose amplitude changes from pulse to pulse, as in curve (B). Note that the Doppler pulses and the stationary target pulses have slightly different shapes at the tops. The clutter filter can be thought of as recognizing the difference and rejecting the echo from the stationary target.

Next, Doppler-frequency pulses are rectified to give the form shown in curve (C); they are then filtered and limited to give the form shown in curve (D). The rectification reintroduces the repetition-frequency components (nf_r), and the final waveform has range information in the form of distances between leading edges. The video signal is presented on a PPI display to measure the range of the moving target.

MTI Radar

Although pulse-modulated Doppler has good rejection of ground clutter, and emphasis in development for naval applications is on MTI. This is due to the better resolution of MTI radar.

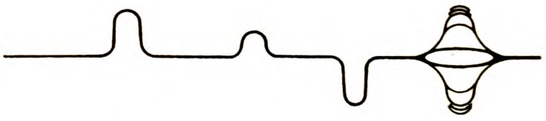
Although MTI radars are pulse radars, the principles of MTI and pulse-modulated Doppler radars are so similar that the basic principles of MTI will be discussed at this time.

If the echoes from fixed and moving targets, fig. 8-63, are presented on an A scope, they appear as shown. The echoes from a moving target vary in amplitude and give the signal a fluttering appearance; the echoes from a stationary target have steady amplitude. The pulse-modulated Doppler system uses filters to reject the pulses of constant amplitude, whereas MTI systems use pulse-to-pulse cancellation of echoes. The first four curves illustrated are the four individual traces shown superimposed on the A scope. If the signals of sweep 1 are delayed for an interval equal to the repetition period and then subtracted from the signals of sweep 2, all signals of constant amplitude are cancelled and only variations between successive pulses remain. The last three traces show the cancelled signals.

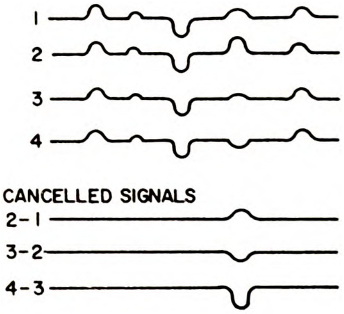
One method of delaying the pulses is to use a supersonic delay line. The subtraction process can be carried out continuously by the arrangement shown. The video signals from the receiver are sent through two channels, one of which contains the delay line. The undelayed echoes and the delayed echoes are then compared in a subtraction circuit, after which the difference signals are presented on an A or PPI indicator. The delay line and subtraction circuits perform the function of the clutter filter and range-restoring elements in the pulse-modulated Doppler system; that is, pulses of constant amplitude are rejected and Doppler pulses of variable amplitude are accepted.

One type of supersonic delay line consists of two electromechanical (piezoelectric) transducers separated by a medium in which the pulse travels at reduced speed. The video signal is introduced between the mercury in the end-cell and that in the delay tube. The voltage across the piezoelectric crystal deforms the crystal. The vibrations are communicated to the mercury in the delay line as a supersonic wave, which travels in mercury at the velocity of 1,700 feet per second. The length of delay line determines the amount of delay. At the output end, the wave causes the crystal to vibrate and produce an alternating voltage. The output voltage is taken from another end cell. The end cells are used as electrodes to introduce and recover the video signals and also to terminate the delay line with the proper impedance.

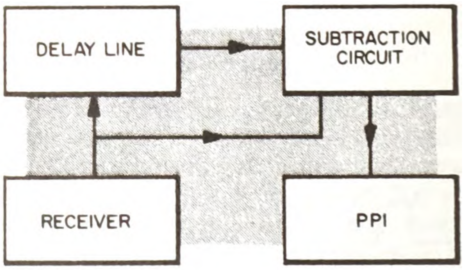
The response of the crystals does not permit undistorted transmission of the video pulses at the input and output. An undamped crystal has



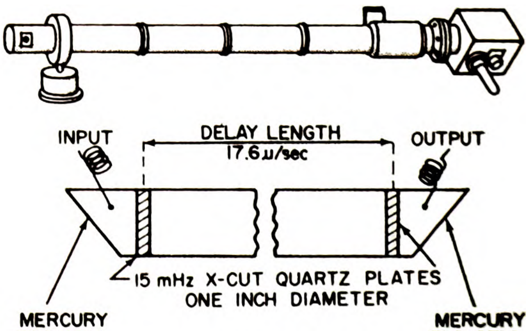
fixed and moving targets



cancellation of echoes



cancelling signals by subtraction



supersonic delay line

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Figure 8-63.—Cancelling echo return signals i the MTI radar.

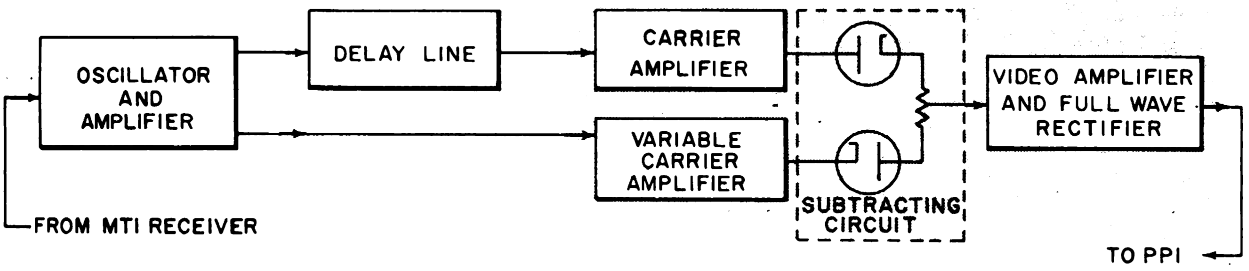

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Figure 8-64.—MTI subtraction circuit.

oo high a Q and cannot transmit microsecond ulses. A critically damped crystal has a Q ear unity, with maximum response at the re- onant frequency of the crystal and zero response t zero frequency. Whether the crystal is damped r not, a video pulse in the shape of a square ave would be distorted. To avoid distortion, he pulses are used to modulate a carrier, the requency of which is the resonant frequency of he crystal.

The video signals from the MTI receiver mplitude modulate a 15-mHz oscillator. The mplitude-modulated carrier is sent through the elay line and then subtracted from the undelayed arrier in the subtraction circuit. The subtrac- on circuit (fig. 8-64) consists merely of two iodes arranged to give opposite polarities at he output, so that signals of equal amplitude roduce zero output.

In addition to the supersonic delay line, another evice for delaying the echo signals in an MTI ystem is a storage tube, which is similar to the onoscope used in television. However, mercury of quartz delay lines are used more often in MTI systems that are now being tested.

A complete MTI system is shown in figure 8-65. As in the simple Doppler system, the echoes are translated to zero frequency by heterodyning in the receiver at the intermediate frequency. The CW reference signal that is used in the heterodyning process is obtained from the coherent IF oscillator. When pulsed, the transmitter starts with random phase from pulse to pulse. The phase of the reference oscillator must be matched, or locked to that of the transmitter at each instant of pulse transmission, since the phase change beating oscillator and returning echo is the basis for the recovery of the Doppler-shift pulses.

An RF locking pulse from the transmitter is used to phase the oscillator. The locking pulse is said to make the oscillator inherent with the transmitter, and the oscillator is called a coherent oscillator or coho.

Various MTI systems are under development for naval purposes. The systems differ in the

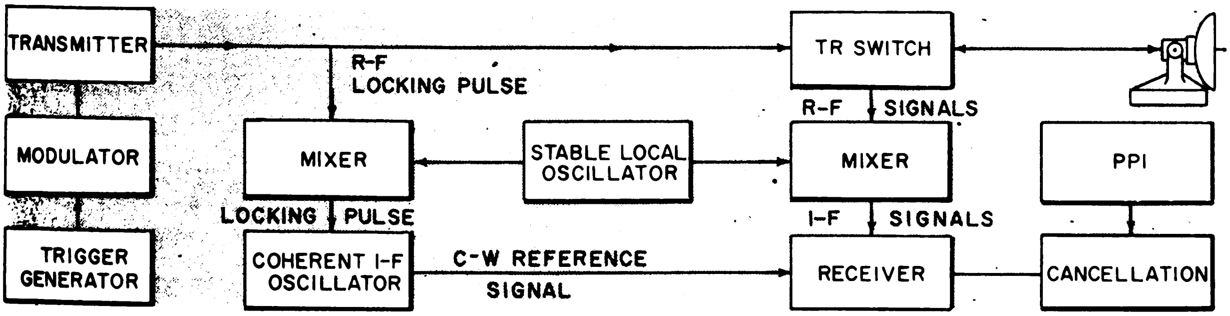

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Figure 8-65.—MTI system, block diagram.

methods employed for interlocking the transmitter and coho at RF or IF frequencies, and in the types and location of the delay and subtraction circuits employed.

Moving-target indication circuits can be added to a radar aboard ships by compensating for the velocity of the ship. The compensation can be done by a phase-shift unit. The phase-shift unit (fig. 8-66) changes the phase of the reference signal at the same rate that the phase of echoes from fixed targets is being changed by the motion of the ship.

COMPARISON OF PULSE AND CW RADAR

The operating principles of the two basic types of radar have been discussed. A brief comparison of certain aspects of each is desirable to better understand the employment of these radars.

By now it should be clear that pulse radar measures range to a target by timing a pulse of RF energy in transit to and from a target. The more accurately the pulse radar can measure this time, the more accurately it can measure range and fix the target's position. On the other hand, CW radar has no inherent means of measuring range, since there are no pulses to time. Various means of range measurement using a CW system are possible, but they are at best compromises and inferior in accuracy when compared to pulse radars. Therefore, if a given radar system must geographically fix a target's position accurately, a pulse radar would be best.

Pulse radars can measure range, but cannot reject clutter echoes from fixed targets. The CW Doppler radar can distinguish between fixed and moving targets and measure range rate. Therefore, when a system requirement is the measurement of range and range rate of a moving target, a combination of pulse and CW can be used.

In the above paragraphs, no attempt has been made to establish one system or radar type as being better than the other. All systems have their advantages, disadvantages and areas of best application. Each system must stand on its ability to perform a particular mission.

RADAR COLLIMATION

Radar collimation provides for the parallel alignment of the radar beam axis and optical axis of the radar antenna. This can be accomplished by the use of a shore tower on which is located an optical target and a radar horn antenna (fig. 8-67). The horn antenna is connected to RF power measuring equipment and is properly positioned in relation to the optical target. The horn antenna displacement, relative to the optical target, would be determined by the relative displacement of the two axes (optical and RF) as measured at the radar.

To check or adjust for parallelism of the two axes, the radar antenna is trained and elevated until the cross hairs of the optical sight intersect the optical target. At this time, maximum RF energy should be directed into the horn antenna as measured by the power measuring equipment. If not, the axes are not collimated and appropriate adjustment procedures should be accomplished. In brief, this requires that one

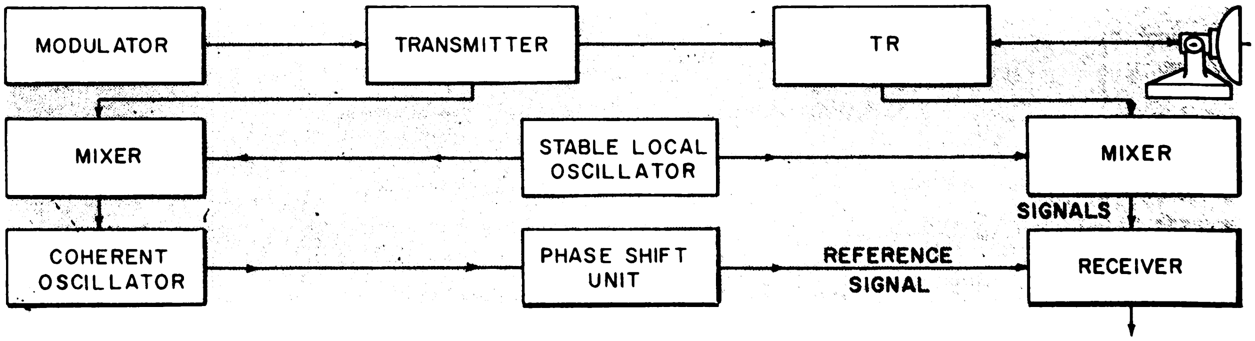

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Figure 8-66.—Compensating for own ship movement.

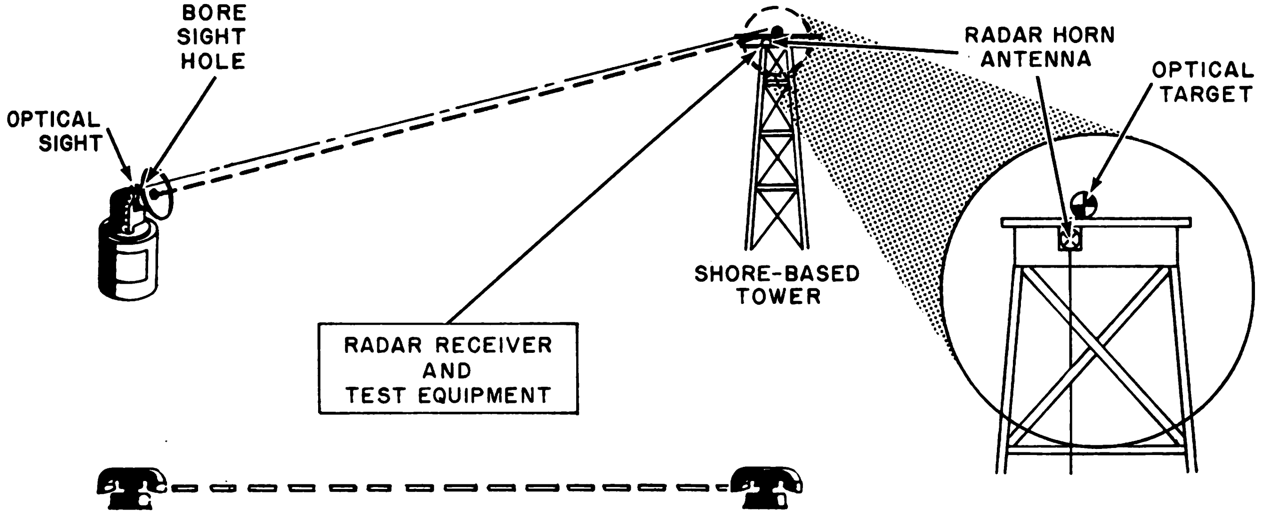

Figure 8-67. — Radar collimation.

xis be aligned to the other until they are arallel. Step by step procedures for accomplishng this alignment varies between radar installaions. You should refer to applicable radar equipnent documentation for information of this nature.

Collimation of the tracking/acquisition RF xes of a radar to its director (optical axis) s necessary to (1) ensure accurate definition of arget position by the director to the fire conrol computer, and (2) to ensure adequate illumnation of the target by a continuous-wave illumnating beam. The measurements that must be nade in order to determine if the radar is ollimated to the director require use of a hore tower (fig. 8-67). Other measurements and linements requiring the shore tower are measrement of angle error sensitivity, measurement f the angular position of track transmit axis ith respect to receive axis, and alinement f television cameras.

Collimation requires the use of an antenna nd optical array which is mounted on the hore tower. Antenna/optical arrays are also ounted aboard ship to provide means of accomlishing collimation when shore towers are not vailable. The procedures are basically the ame as those involving shore towers. Allowance, owever, does have to be made for the shorter istances that prevail aboard ship.

RADAR COUNTERMEASURES

A target can defeat a radar system in a variety of ways. Any countermeasure which gives false target information, such as chaff, can be effective since they tend to obscure exact target position and may overload the radar with false targets. In these instances, the most effective counter-countermeasure is a highly trained operator or an accurate discerning mechanism capable of distinguishing false targets from real ones.

Jamming techniques are similarly effective because exact target position is lost in the jamming signal. Delay circuits, homing devices, and randomness of output are all effective methods of countering jamming techniques. Targets capable of carrying even more complex equipment than that required for jamming may actually transmit false positional information that may be picked up and interpreted as energy reflections by the radar attempting to locate it. This method is particularly effective against radar systems relying on the Doppler frequency shift. Since this countermeasure involves not only recognizing a signal, but also computing and transmitting another signal, it cannot as yet be accomplished instantaneously. Therefore, coded or random pulse trains are effective counter-countermeasures at present.

Spoofing or electronically simulating targets is also employed to overload and fool radar systems. Again, coding or randomness of outputs can successfully defeat this form of countermeasure.

It is essential that a radar be flexible enough to handle all of the countermeasures it can expect. It is also imperative that the radar recognize false targets in their initial stages. Once it begins tracking them, their purpose has been accomplished and if there are enough of them the radar will overload and break down. Splits and merges are conditions inherent to the multiple target problem and add to tracking difficulties. Splits occur when a contact detected by the radar as a single target splits into two more discernable targets. Merges occur when several targets come together so that they appear as one target to the radar.

In this sense, breakdown does not mean that the radar actually ceases to function, but, rather, that it is no longer furnishing an appreciable portion of the target information needed. The ability to pick out and ignore false targets is therefore of prime importance in handling multiple target situations.

There are many variations of countermeasures in existance and also numerous new possibilities; therefore, as can be seen from the previous discussion, enemy jamming can offer a radar operator a real challenge. You must not, however, feel that jamming is so intense and effective that nothing can be done about it.

It has been found that quite often, when an inexperienced operator encounters jamming, even of a very slight amount, he becomes confused and frustrated because of his inability to handle the situation, and quite early in the game wants to "throw in the towel."

Remember that, during jamming, you are not expected to have all target information all of the time as when in normal operation, since with modern weapon systems a kill can be obtained even with only partial target information.

Recognizing and identifying radar countermeasures is over half the battle. If you have succeeded in accomplishing this, you have eliminated the elements of confusion and surprise which the enemy has tried to force on you. You are then able to cope more efficiently with the countermeasures being applied, and you should be able again to gain useful information from your fire control radar.

A detailed discussion of Electronic Counter-Countermeasures (ECCM) and the anti-jamming circuits designed into fire control radars is not feasible in this manual because of its security classification. You can obtain more information on ECCM techniques and devices by studying any one of the three supplements to this manual.

CHAPTER 9

PRINCIPLES OF SERVOS

INTRODUCTION

Servomechanisms, called servos for short, have countless applications in missile fire control. Directors, radar antennas, computing devices, and missile launchers are positioned by servos. In chapter 2, we referred to the guided missile as a flying servomechanism. The operation of modern fire control equipment is almost fully automatic, and largely dependent on data from remote sources. To obtain smooth, continuous, and accurate operation, the information flow is normally best controlled by synchros. But the power produced by transmission devices such as synchros is not large enough to do appreciable amounts of work. Therefore, servo systems are necessary for the precise control required by our nissile fire control systems. In fact, the use f servos has increased tremendously as our ire control systems have become more and more utomatic in their operation. A sound understanding of the principles of servomechanisms s a must for fire control technicians.

EFINITION OF A CONTROL SYSTEM

A control system is a group of components, ystematically organized to perform an end unction. Generally, a control system has a rge power gain between input and output. he components utilized may be mechanical, lectrical, hydraulic, pneumatic or various cominations of these. Systems will range from imple motor control systems to very complex omputer-operated missile control systems.

LASSES OF CONTROL SYSTEMS

There are many types and classes of conol systems, but all of them fall into two asic categories: OPEN LOOP CONTROL SYSEMS and CLOSED LOOP CONTROL SYSTEMS. Each can be mechanical, electrical, pneumatic or hydraulic. The closed loop control system in particular, being automatic in nature, is further classified by the function it serves (e.g., controlling the position, velocity or acceleration of the load being driven).

BASIC OPERATING PRINCIPLE OF THE OPEN LOOP SYSTEM

An open loop control system is controlled, directly and solely, by an input signal. A simple system of this type would be an amplifier and motor, in which the amplifier receives a low level input signal, which is amplified to drive the motor that performs some task. Note that the motor output, the shaft velocity, is not directly related to the input signal. Therefore the input signal to the amplifier remains the same regardless of the shaft velocity, even though the shaft velocity may vary under different load conditions.

Open loop control systems generally require a human operator who will vary the input signal to meet the end requirement. Manually operated machine tool drives and controls are examples. The human operator continually makes adjustments to speed and travel.

Open loop control systems, generally requiring manual control, have been used in wide ranges of consumer, industrial, and military applications. However, the advent of automation is bringing about the widespread use of the closed loop control system.

BASIC OPERATING PRINCIPLE OF A CLOSED LOOP SYSTEM (SERVO)

The closed loop control system is more commonly called "servo" system. The word "servo" is derived from the Latin "servus" meaning slave.

A servo will follow a command, with no need for a human operator to continually adjust the input to meet varying output conditions.

To be classified as a servo, a control system must:

1. Be capable of accepting an order which defines the desired result.
2. Be capable of evaluating the present conditions.
3. Be able to compare the desired result with the present conditions and obtain a difference or an error signal.
4. Be able to issue a correcting order, determined by the error signal, which will properly change the existing conditions to the desired result.
5. Have the means to obey the correcting order.

The operation of a servo system is controlled by the "error signal." The error signal is derived from the algebraic sum of the input or "command" signal and the response signal. Response is a measurement of the output of the servo, which may be position, acceleration, or velocity. The command signal and response signals must always be in opposition so that the algebraic sum will be zero when the load meets the command conditions. Thus, if the command is a positive direct current (d.c.) signal, the response must be a negative d.c. signal. If the command signal is alternating current (a.c.), the response must be 180 degrees out of phase.

For example, if an input signal, at the point where the signals are summed, is measured as +10 volts and the response signal measured -5 volts, the error signal would be +5 volts (the algebraic sum of +10 volts and -5 volts). Alternately, if the input was -10 volts and the feedback was +5 volts, the error signal would be -5 volts.

In both examples, the load (director, missile launcher, etc.) is going to be driven until the response signal is equal and opposite to the input signal.

Response obviously is the key to the successful operation of a servo. The response signal is that which enables us to precisely control fire control equipments in response to orders or data from some remote station. Response, however, is not all that's necessary for a true servo. In fact, response satisfies only one of the five requirements of a servo. It provides the means of evaluating present conditions and is only a part of the complete servo loop. Let's take a closer look at a complete servo loop. We'll start with an analysis of the characteristics of servomechanisms.

Servomechanism Characteristics

A SERVO IS A CONTROL DEVICE. The basic job of the servo in figure 9-1 is to position a load. The load may be a director, a radar antenna, a computing device, or a hydraulic valve. The load is attached in some manner to the output of the servo. Consider a director. Its position is controlled in accordance with train and elevation orders which are inputs to the servo.

A SERVO IS A POWER AMPLIFIER. The input to a servo is usually a very small signal. It is too weak to move the load by itself, so some sort of power amplification must take place within the servo. Again take as an example a servo used to position a director. To develop enough power to move the great weight of a director requires currents in the ampere range. Therefore, most servos you will work with have one or more amplifying stages. The amplifier may be electrical, electronic, hydraulic, or two or more of these in combination.

A SERVO IS A CLOSED-LOOP SYSTEM. Look again at figure 9-1. You can see that the response line runs from the output to the circle marked error detector. This response is a communication channel which reports the speed or position of the output back to the error detector. To see how response works, assume that the input is a mechanical signal telling the output to move to a certain position. The response

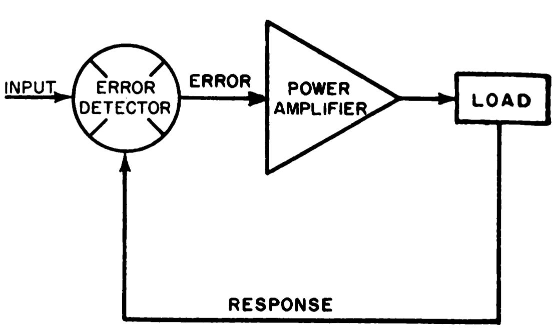

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Figure 9-1.—Diagram of an elementary servo.

ignal reports the position of the output to he error detector. The error detector performs simple mathematical operation: it subtracts he output from the input to get the amount of ifference, or error. And the error, rather than he quantity market input, is the actual input to he amplifier.

Note that when the response equals the input, he error signal is zero. But whenever the esponse differs from the input, an error signal s developed. The error signal drives the output such a manner as to reduce the error signal. Keep in mind that response can be trans- itted electrically, hydraulically, or mechan- ally in a servo.

A SERVO IS AN ENTIRE SYSTEM. It cannot onsist of a single component. It must have the inimum number of components we have shown the diagram of figure 9-1. There is no w against a servo having more sections than e ones we have shown. And they usually do. ut regardless of the number of parts in a servo, ey all work together as a system or team. nd this system concept is important. A servo not an isolated motor or power amplifier, but ust be considered as an entire system of terconnected components. Together, these com- nents measure, transmit, compare, amplify, d control quantities.

nctional Sections of a Servo

Figure 9-2 is a three-unit diagram of the ementary servo shown in figure 9-1. Each it has a label that describes its function. Our new diagram differs from the first e in that the power amplifier has been divided o two parts: an AMPLIFIER and an ERROR REDUCER. The amplifier increases the weak error signal, and it controls the error reducer. We have coined the term error reducer because the name closely describes the function of this servo section, which is to drive the output of the servo until it is equal to the input, thus reducing the error nearly to zero. Keep in mind that there can never be zero error. The error reducer must receive an error signal before it can control the output. However, the error signal should be kept as small as possible.

In the servo in figure 9-2 the input, output, and response devices are mechanical shafting; the error detector is an electromechanical device; the amplifier is electronic; and the error reducer is an electromechanical unit.

Earlier, we described a servo as any device that uses the response to cancel the input signal. It can also be defined as a mechanism whose output tries to reproduce its input. Let's look at how the servo diagramed in figure 9-2 works, based on this point of view. Assume that the input and the output shafts are at the same position. There is no error between them, and so there will be no error signal to the amplifier. Therefore, the error reducer will not receive a correcting signal and the servo will not move. But if the input shaft is suddenly turned to a new position, there will be an instantaneous angular difference between the positions of the input and output shafts. Where is this difference detected and measured? The answer is, of course, at the error detector. The input and response shafts are both inputs to the error detecting device, which, as we said before, is electromechanical. Since the response shaft is geared to the output shaft, the response duplicates any position and motion of the output. In other words, knowledge

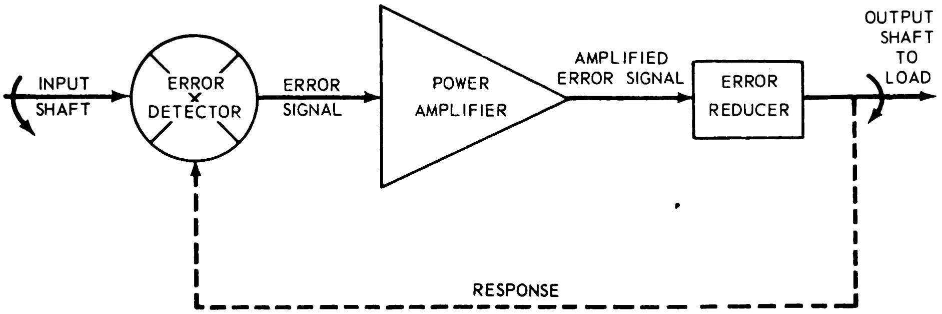

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Figure 9-2. — Diagram of an elementary servo.

of what the output shaft is doing is fed back over the response line to the error detector. Here, the positions of the input shaft and output shaft are compared. The error detector measures any difference between them, and then it does something more. It changes mechanical position error into an electrical error signal. The electrical error output of the error detector is directly proportional to the angular difference between the input and output shafts.

The electrical error signal is relatively weak. So, it must be amplified. After it is amplified, it is sent to the error reducer. Here, the error signal is changed from its electrical form to a proportional mechanical signal. Now the error reducer drives the output shaft in a direction which reduces the error between the output and input shafts. As the output shaft turns, so does the response line, but it turns in a direction that reduces the difference between the input and response signals. When the output and input shafts are in agreement, the output of the error detector is zero. The amplifier "sees" no signal at its input, and the servo stops.

Now, if we turn the input shaft at a constant velocity, the output shaft should turn to the same position as the input shaft, and follow it at the same speed and in the same direction. If the input shaft were to speed up, then reverse its direction, the output shaft should faithfully reproduce these mechanical gymnastics; and all the while the two shafts should remain closely aligned. If at any time they do not, then the error detector will produce an error signal. This signal is amplified and sent to the error reducer. It then drives the output shaft until the error between the input and output is as nearly zero as possible. When this condition exists, the servo is said to be "nulled." Other terms that describe zero or nearly zero error are: synchronized, in synchronism, and in correspondence.

In the preceding pages of this chapter we have given you a general idea of the functional sections of a servo and what they do. You learned that the input is the controlling quantity. We described it as the displacement of a shaft. In practical servos or power drives the input is generally an electrical quantity which represents a shaft position. The servo error is the difference between the input and output of the servo. The error detector is the device which compares the input with the servo output. The error reducer is essentially the prime mover of the servo. It is controlled by the amplifier section, which simply increases the strength of the error signal so that it can move the error reducer. We mentioned the load earlier. While the load, strictly speaking, is not a component of the servo, load characteristics (size, weight, etc.) have an important bearing on the design and operation of the servo.

Signal Types

A servo's output is an accurate duplication, with an increase in power, of the input order signal. The order signal represents the desired action and therefore determines the servo's response. The order can be a position, a velocity, or an acceleration signal. Let's consider the three types of order signals. Position is a relative quantity which indicates a place or point in a scale of measure or reference frame. Hence position is a scalar quantity and it has no further meaning. Movement from a position results in a displacement. Displacement is a vector quantity having both magnitude and direction. If we time a displacement we can obtain a velocity. Velocity is a timed displacement; that is, the rate of change of position. Velocity then is a vector quantity being derived from displacement, also a vector quantity. (Incidentally, speed is a scalar quantity having only magnitude.) A change in velocity is an acceleration. Hence acceleration is a vector quantity. Strictly speaking, an acceleration is a change in velocity and therefore can be either an increase or decrease in speed or a change in the direction of motion.

Scalar quantities can be combined by simple arithmetic. Vector quantities, however, are more difficult to combine. Since both direction and magnitude are involved, vector addition is required. It is the job of the error detector in a servo to combine the input and response signals whether they are vector or scalar quantities. Vector quantities can be combined by simple arithmetic if their directions are along a common axis. In servos the output is a duplication of the input and therefore their directions mus be common.

Order signals often must be converted from one type to another. For example, the fire control radar will measure the displacement o a target from the line of sight. From this displacement a velocity is derived to change the rate of motion of the director. On the other han we may have a computed rate of motion an require the displacement which will occur durin a given time. We can change the signal because displacement, velocity, and acceleration are functions of each other and each is a derivative of the other. A derivative is a quantity which is obtained from another. If we know that a displacement occurred in a measured interval of time we can derive the rate of motion. And it follows that if we know the rate of motion we can derive the displacement which will occur during an interval of time. These signals are obtained in servos by integration. We will not go into integration here since it can be reasoned that if one of the quantities and time is known, the other quantities can be derived.

CONTROL SYSTEM TERMINOLOGY AND SYMBOLS

Fundamental to understanding control system in any depth is a familiarity with terminology, definitions, and symbols used to describe a system and its characteristics. The subject is often misunderstood or thought of as complex because the representative terms are not understood.

Control systems simply combine known principles, and some way of describing their characteristics is essential, resulting in the new terminology. The symbols are simple "shorthand," or a way of abbreviating the terminology.

Due to the rapid advancement of control systems in recent years, a completely common language has not yet evolved. This has, in part, led to the belief that the subject is complex. Remember that the principles never change; only the techniques and methods of description change. If the underlying principles are understood, then the control systems will be understood.

Terminology, definitions, and symbols will be explained throughout this material, where appropriate.

SCHEMATIC AND BLOCK DIAGRAMS

Examination of an actual physical control system does not explain the functional operation or show all of the physical details. This type of information is, however, shown on one of two distinct types of drawings which are (1) the schematic and (2) the block diagram.

A schematic diagram illustrates a system by showing physical connections between component symbols. A schematic does not show flow of information, the function of a circuit or the function of individual components. Schematic diagrams are used in the assembly, installation, maintenance and troubleshooting of electronic circuits. "One-function" prints, each covering the components and connections for only a single quantity (such as missile orders, director train, range, etc.) of a system, have been developed to simplify troubleshooting of highly complex fire control systems.

A block diagram, on the other hand shows (1) the elements of functional interest and (2) the flow of information but disregards the physical aspects shown in a schematic.

The two types of motor (fig. 9-3) differ physically but perform the same end function. Therefore, the block diagram can represent either motor since it is concerned with functional elements of interest. The arrowed lines denote the direction of information flow and should be labeled to indicate the element of interest.

The output element or interest could be shaft position or velocity, depending on its functional application. If the output of interest were velocity, the block diagram output would be so labeled and

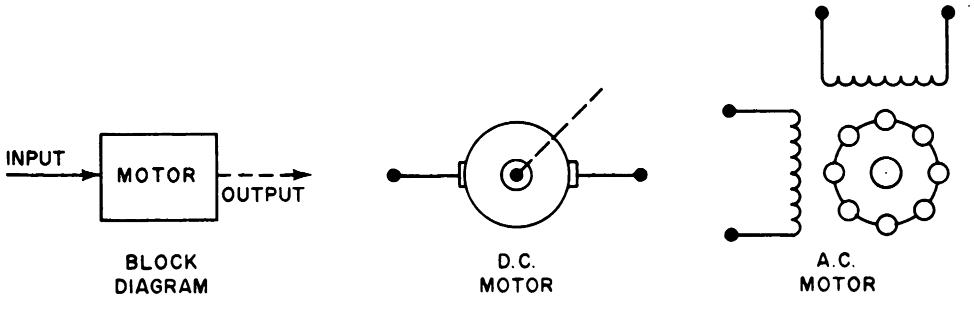

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Figure 9-3. — Block diagram and schematic symbols of motors.

the input element of interest would be labeled as voltage, since a motor's velocity depends on voltage. Alternatively, if the output of interest were position, which is a component of torque, the output would be labeled position and the input labeled current, since a motor's torque depends on the amount of current present.

The block diagram can be used to represent any component or group of components. For example, a single block can represent a complete amplifier, with the input and output elements of interest labeled. A block can represent a hydraulic piston, in which case the input element of interest might be fluid pressure and the output element of interest output force displacement. The arrows point the direction of information flow, regardless of actual direction of current or fluid motion.

It should also be appreciated that the element of interest is not the only element going in or out of the block. If current is present there must be a voltage causing the current, but only the element of interest is labeled.

When various component blocks are connected to form a system the output of one becomes the input to the next. Figure 9-4, in block diagram form, shows an open loop control system.

The block diagram of figure 9-5 shows five important control engineering symbols and has a new block added entitled "response transducer." The term transducer is generally defined as a device that converts one form of energy to another. In the control system context it represents the components that measure the controlled element of interest. Its input is converted to a compatible signal and is fed back to a point where it is summed with the input signal to generate the system error signal. It is the accepted term for the response components in block diagrams since the block diagram shows only signal information and functional elements of interest. The specific response components will vary with the type of systems which are specified only in the schematic diagram.

SYMBOLS AND DEFINITIONS

The control engineering symbols are:

1. The Greek letter sigma, meaning summation, surrounded by a circle. This is the summation, or "sum point," where the reference and response signals are summed to derive the error signal that controls any servo.
2. The letter R stands for the "sum point input reference signal". The reference signal may directly be the input signal but in some instances, as will be subsequently shown, the input signal may be changed before reaching the sum point to make it compatible with the feedback signal.
3. The letter B is the symbol for the response signal; the sub p with this symbol identifies signal content as being position related.
4. The letter C is the symbol for "output variable" and the sub p indicates that the variable of interest is position.
5. The letter E is the symbol for the "error signal".

The symbols can be enlarged with additional sub letters to give further information as in the case of R, B_p and E, to show they are either voltage or current.

SYSTEM TYPE IDENTIFICATION

A servosystem, by convention, is identified by its "prime mover" which is a control system term for the component that does the actual work. For example, electrical motors and hydraulic and pneumatic pistons are prime movers. A servosystem that employs a d.c. or an a.c. motor is called a d.c. or an a.c. servo.

One employing a pneumatic or hydraulic piston is called a pneumatic or hydraulic servo. With the advent of combination systems such as a d.c. motor being controlled by a.c. components and signals or a hydraulic system controlled by d.c. components and signals, the

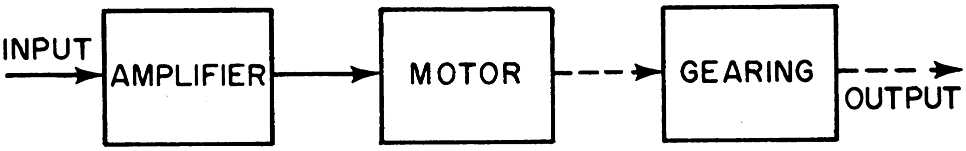

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Figure 9-4.—Block diagram of open loop control systems.

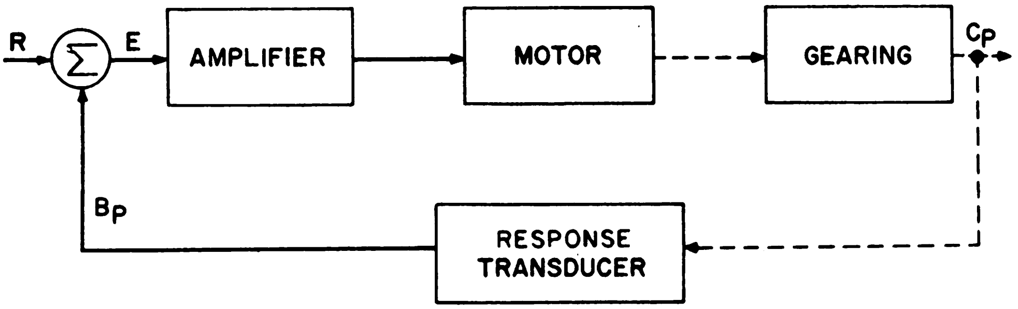

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Figure 9-5.— Block diagram of position servosystems.

conventional identification is often confusing. Understanding will result if both the prime mover and method of control are identified whenever they differ. The case cited above of a d.c. motor being controlled by a.c. components and signals should be described as an a.c. control d.c. motor servo system in lieu of describing it as a d.c. servo system.

All types and classes of servos employ the same basic servo theory and have similar dynamic operating characteristics. The a.c. servo, so called because it employs a.c. components and signal information, was the first widely applied servo. It came into wide use in military applications during the latter part of World War II. No one type of servo can meet all requirements so other types of systems and components were developed, leading to d.c., hydraulic, and pneumatic servo systems.

Electric servos account for the majority of application; however, all types are in widespread use.

A.c. servo components operate on more complex electromagnetic principles and are controlled by a.c. modulated signals that tend to obscure the real servo principles. The d.c. servo n certain respects is comparable with hydraulic and pneumatic servos which often employ d.c. control techniques and components. It makes a good example system for a student of basic servo theory because all of its signals, including he all-important error signal generation, are down around zero frequency. When dealing with d.c. or near zero frequencies, signals can be easily observed and measured with uncomplicated instrumentation.

TYPES OF POWER SYSTEMS

The input signal to a servo is weak, and a large boost in power is needed before the servo can do its job. The type of power used in a servo is determined by its job. Electric servosystems are used with light loads. But if the load is large and variable, the servo must have an amplifier to increase the signal power supplied the error reducer. Most servos in fire control equipment are electromechanical; the amplifier is electronic, and an electric motor is used as an error reducer. There are, however, a few electrohydraulic servos in fire control. In the hydraulic servos the input signal is amplified in an electronic amplifier. The amplified signal controls an electric device which in turn controls the hydraulic power system.

Each type of power has advantages. The electric servo is the simplest. An electronic amplifier is flexible, and can adapt the servo to the load. Thus the electronic system provides positive control at variable speeds. Hydraulic systems cannot be backed down by the load. Thus they are used with heavy loads subject to sudden and drastic changes. Radar antennas which have a large area exposed to the effects of wind force are examples of this type of load.

ELECTRIC SERVO

In an electric servo, a bearing-mounted synchro operates a set of contacts which control the supply voltage to a servomotor. The motor will drive whenever the synchro closes the contacts. Response from the motor will drive the synchro in the opposite direction from the synchro's signal, and open the contacts. Thus the servo operates until the synchro signal is reduced to zero. Figure 9-6 shows a bearing-mounted synchro and figure 9-7 shows the electrical arrangement of the servo. The servomotor is a 115-V a.c. motor with split phase operation. The capacitor in the circuit shifts the phase of the voltage to one of the motor's windings. The contacts determine which winding will receive the shifted voltage and hence which way the motor will drive. One side of the line voltage is connected to the common point between the stator windings of the motor. The other side of the supply is connected to the center contact which is connected to the rotor of the synchro. A signal to the synchro will cause the center contact to rotate and to complete the circuit to either the left- or right-hand outer contact. Note that either of the outer contacts will complete the circuit to the motor, but by separate paths. The capacitor will be in series with one of the motor's windings. Which winding is determined by the contacts, hence by the synchro signal. The capacitor will shift the phase relationship of the voltage applied to the other windings. The motor will drive until response opens the contacts.

The advantage of electric servos is their simplicity. Their disadvantages are the lack of speed control and their limited current-carrying capacity. The servo is either synchronized or driving, and thus is strictly a position control. The low torque of the synchro limits the size of the contacts and hence their current-carrying capacity. This, in turn, limits this type of servo to light loads.

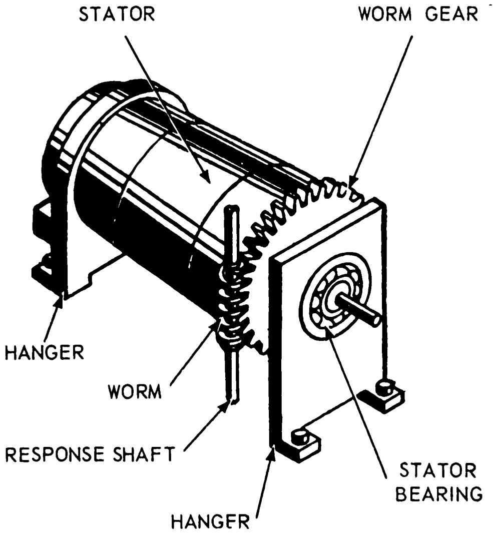

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Figure 9-6.—Bearing mounted synchro receiver.

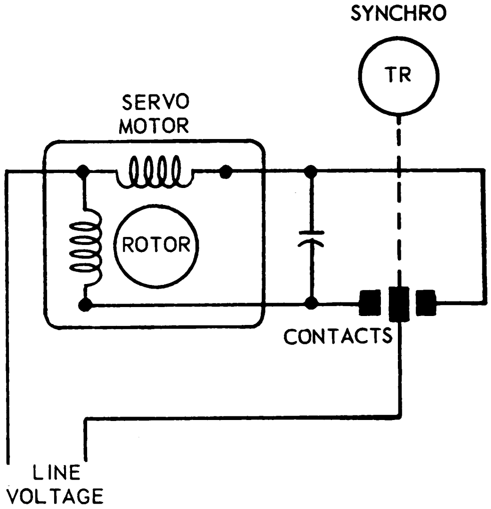

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Figure 9-7.—Electrical servo.

ELECTROMECHANICAL SERVO

The servosystem represented in figure 9-8 is an example of an electromechanical servo. This particular servo employs a synchro transmission system for the transmission of radar range information from a fire control radar range unit to a computer range servo. A study of synchro data transmission will be examined in chapter 11.

Assume that the fire control radar has measured target range at 10,000 yards. The CX in the radar (fig. 9-8), will transmit range to the CT in the computer. Assume that the range servo in the computer is at 9,000 yards. Hence the CT, the error detector, will not be at its null position. The error signal from the CT will be proportional to the 1,000 yards displacement between the ordered position and the actual position of range in the computer. The servo will drive until response positions the rotor of the CT at its null position, which represent 10,000 yards range.

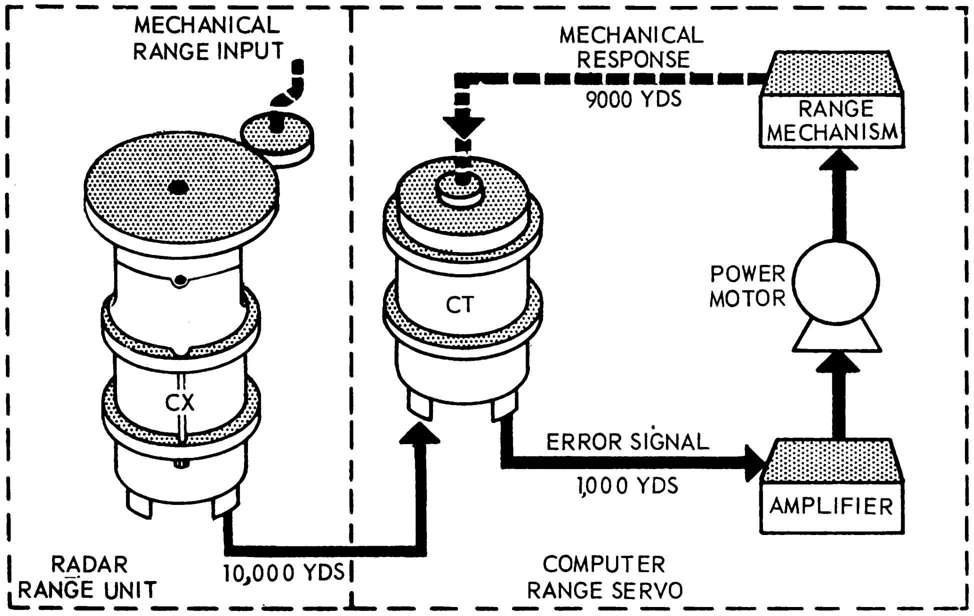

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Figure 9-8.—Position servo.

The electromechanical servo just presented is only an example of an electromechanical servo. Other devices such as potentiometers, gyros, and resolvers can cause a servo to be classified as electromechanical. In chapter 6, you studied servo application of resolvers when you were learning how resolvers are used for composition. Our forthcoming example of a position servo utilizes two potentiometers. Gyros and their role in servosystems will become apparent in the next chapter.

To this point we have not said much concerning servoamplifiers. Obviously the primary function of the amplifier is to increase the strength of the error signal. But an amplifier has many features which can be used to improve the servo's operation. Many types of amplifiers are used in servos. Therefore, it is not practical to discuss individual amplifiers at this time. We will discuss some of the advantages of having an amplifier in a servo.

An amplifier can increase the signal power to a practical level. The amplifier may be made senstitive to signals with a certain frequency, amplitude, type of voltage, and phase or polarity. The amplifier isolates the signal source from the load. The error signal feeds into the fairly constant impedance of the amplifier's input circuit, and not into the variable impedance of the load. At the same time, however, the amplifier's gain can be varied by feedback signals to automatically adjust the amplifier's output to compensate for the condition of the load.

The theory of operation of electromechanical servos is identical to that of all closed-loop servos. Response from the output is fed back to the input to null the error signal. The amplifier has a large power source which is controlled by the low-powered error signal. The amplifier can detect the direction in which the load must be moved by the phase or polarity of the error signal. The amplitude of the error signal determines the amount or the velocity of the servo's output.

ELECTROHYDRAULIC SERVO

Hydraulic components used in servomechanisms are frequently found in weapons systems. Hydraulic power devices, such as motors and associated control valves,have an advantage of a response much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, have very high accuracy, and are well adapted to heavy loads.

The essential components of a hydraulic system are:

1. Source of high pressure oil and sump to receive discharge oil.

2. Control valve and means of employing an actuating signal.

3. Actuator (motor or cylinder).

Hydraulic Transmission Assembly

The hydraulic transmission assembly (fig. 9-9) consists of a variable displacement pump (A-end) and controls, and two fixed displacement motors (B-ends). The variable displacement pump is driven at a constant speed by an electric motor. The fluid flow from the A-end pump to the B-end motors is governed in volume and direction by the position of the A-end yoke which responds to the train error signal from the train servoamplifier. The B-end motors are connected through drive-left and drive-right train gearboxes to the train bull gear.

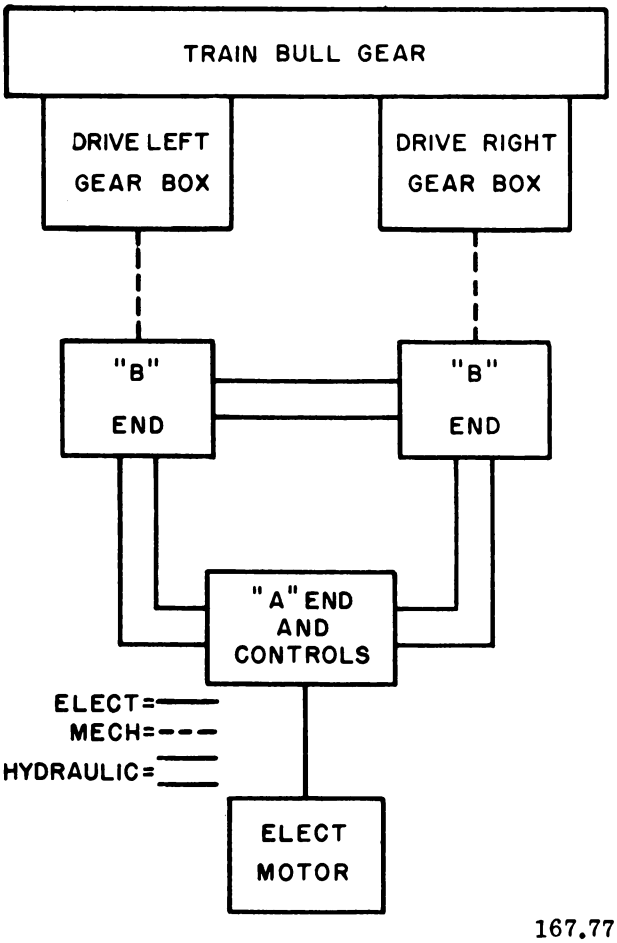

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Figure 9-9.—Simplified hydraulic transmission system.

The A-end is driven by the electric motor to provide the varying nonpulsating flow of hydraulic fluid which is required by the system to control the position of the load (radar antenna or director). This flow of hydraulic fluid under pressure is used to actuate the two B-ends.

The B-end motors are employed in the hydraulic transmission to convert hydraulic energy to mechanical energy. The drive shafts of the B-ends are connected to a gearbox containing gears that mesh with the director's gearing (bull gear).

The two B-end motors, connected hydraulically in series, are used to drive the train member. High-pressure fluid is applied to only one of the B-ends at a time, depending upon which direction the train member is to rotate. The other B-end is then driven by the train bull gear, and functions effectively as a low-pressure pump. A hydraulic pressure is maintained on each B-end inlet by the replenishing pump. This keeps the motors tending to rotate in opposite directions and thereby prevents backlash in the gear train. The replenishing pump also replaces fluid which is lost in the high-pressure circuit by leakage and thus prevents cavitation.

The operation of a hydraulic motor can be considered as exactly opposite to the operation of a hydraulic pump. A pump is driven by mechanical means and produces flow. The motor is driven by fluid flow, the energy of which is transformed in rotary mechanical motion.

Servo Control Loop

The control of the hydraulic transmission assembly is provided by a closed servo loop, figure 9-10, which consists of the train servoamplifier, torque motor, control pilot valve, power piston, A-end yoke, and yoke synchrotransmitter, B01. The train servoamplifier supplies a directional drive signal to the torque

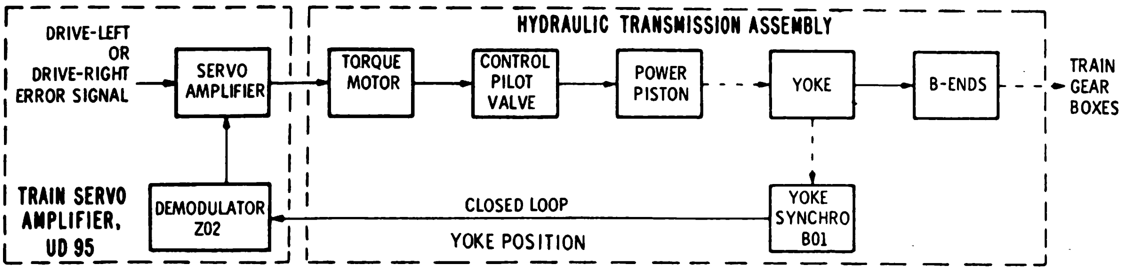

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Figure 9-10. — Train servo control loop, block diagram.

motor which in turn controls the operation of the control pilot valve. The control pilot valve then operates the power piston which is connected to the swivel yoke in the A-end. Since the angle of the yoke determines the direction and velocity of train rotation, synchro transmitter B01, connected to the yoke, provides a yoke position (train velocity) feedback signal to the amplifier through demodulator Z02 in the train servoamplifier, thus completing the control servo loop.

When the train member is to be rotated, either a drive-left or a drive-right signal from train servoamplifier is applied to the control windings in the torque motor, figure 9-11. This error signal introduces an unbalance between the currents in the two windings. These currents create an unbalance in the magnetic forces in the windings which is proportional to the error signal. These forces position the armature accordingly. The armature, mechanically linked to the control pilot valve, moves in the direction required to produce an acceleration in train until the yoke reaches the required position. When this point is reached, the feedback signal applied to train servoamplifier from yoke synchro B01 nulls the drive signal to the torque motor. The armature of the torque motor is pivoted on torsional springs which tend to return it to ts neutral position when the unbalancing currents are removed from the solenoid windings. A pin s attached at the extremity of the armature. This pin enables the yoke power limiter feedback fork n the power mechanism to impart motion to the rmature of the torque motor.

The control pilot valve determines whether the large area of the power piston receives control pressure or sump pressure. In its neutral position, this control pilot valve blocks off both these supplies to the large area of the power piston.

The power piston is connected directly to the A-end yoke through a pin and link. Any movement of the power piston from its neutral position swivels the yoke and thus initiates pumping action by the A-end pump. The power piston operates on a differential pressure principle. The control-pressure fluid acts against the lower side of the piston on an area which is half that of the upper side. When the upper side also receives the control-pressure fluid, an unbalanced force results and the piston is driven downward. When the upper side is connected to the sump, the piston moves upward. When the control pilot valve is at its neutral position, the fluid, in the large area side of the power piston and in the connecting line to the control pilot valve, remains at the pressure established before the valve assumed its neutral position. Thus, the power piston is maintained at a fixed position. In addition, the amount of fluid the control pilot valve allows to enter the power piston determines the distance that the piston is displaced.

A synchro transmitter, geared to the yoke, is employed in the hydraulic transmission assembly, to complete the control servo loop. This synchro transmits a signal proportional to the yoke position to the train servoamplifier. Attached to the shaft of the synchro is a split spring-loaded sector gear which meshes with a sector gear pinned to the end of the yoke. Rotation of the yoke imparts motion to the synchro rotor, registering the yoke position. When the torque motor windings are unbalanced by an error signal, the control pilot valve is moved off neutral by the torque motor. This movement

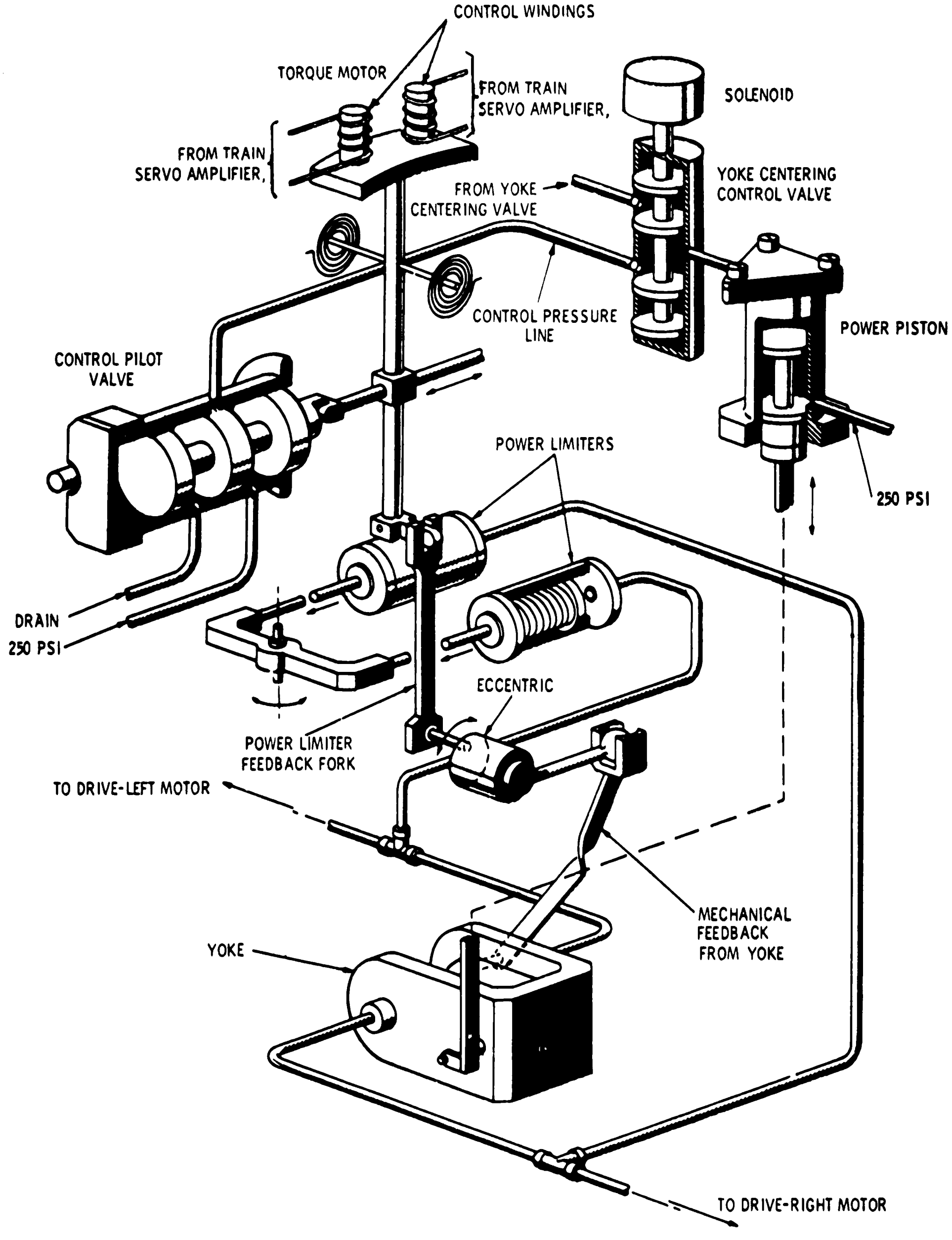

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Figure 9-11.— Train servo control loop, mechanical diagram.

causes fluid to flow into the power piston which in turn causes the power piston, and therefore the yoke, to attain a velocity proportional to the flow of fluid. When the yoke reaches an angular position equivalent to the original torque motor error signal, the control pilot valve is returned to its neutral position. This repositioning action occurs because the synchro positional feedback signal is equal to 180-degrees out of phase with the original error signal and thus cancels the error signal. As the train member is positioned according to the original error signal, the error is reduced to zero. The signal from the yoke synchro then becomes larger than the position error signal, causing the control pilot valve and power piston to return the yoke toward its neutral position.

The sump pressure, previously mentioned, is produced by a replenishing pump which maintains the closed circuit of the hydraulic transmission lines at a specified pressure to compensate for the internal leakage of both the A-end and the B-ends and to prevent backlash.

POSITION SERVO OPERATION

The position servo is one whose end function is to control the position of the load it is driving. It can be used to position an infinite number of devices (i.e., valves, control surfaces, platforms, etc.) The input signal can be a manual input (i.e., in many remote control applications) or from a programmed tape, computer or other source.

The input signal to a servo is outside the servo loop, and so is not really a part of the closed loop servosystem. The input signal is essential to the servo's operation and must be made compatible with the servo's method of mechanization. In this example, a potentiometer will be used to generate the input signal and will be shown in both the system block diagram and schematic representations.

Figure 9-12 is a block diagram model of a d-c position servo. A new block has been added with the letter "A," the symbol for the "reference signal transducer." The input is "V," the symbol for input signal variable and its output symbol is R (the sum point input reference signal to the servo). As stated above, a command potentiometer is employed to generate the input signal, the input signal variable (V) is the shaft angle or position of the wiper arm. The amplifier, motor and gearing blocks are designated G_1 , G_2, G_3. The letter G is the symbol for the gain blocks which are numbered in the example because there are more than one. The response transducer block is designated H, the symbol for feedback blocks, C_p and B_p represent the output variable and response signal, with the sub p again meaning position related. E, of course, represents the error signal and sigma, the sum point.

Note that only G_1 (the amplifier) has power gain, or a higher energy output than the "E" input. The G_2 block (motor) changes electrical energy to shaft velocity or torque and has an energy loss. The G_3 block (gearing) is a mechanical transformer, and also has an energy loss due to friction.

The system can, therefore, be broken down into three distinct sections. They are (1) the amplifier or power gain section, (2) the combined motor and gearing, called the actuator, and (3) the combination of input reference transducers, sum point and feedback transducers, called the error signal generation section.

Assume that G_2 is a 12 volt permanent magnet d.c. motor. The direction of rotation is determined

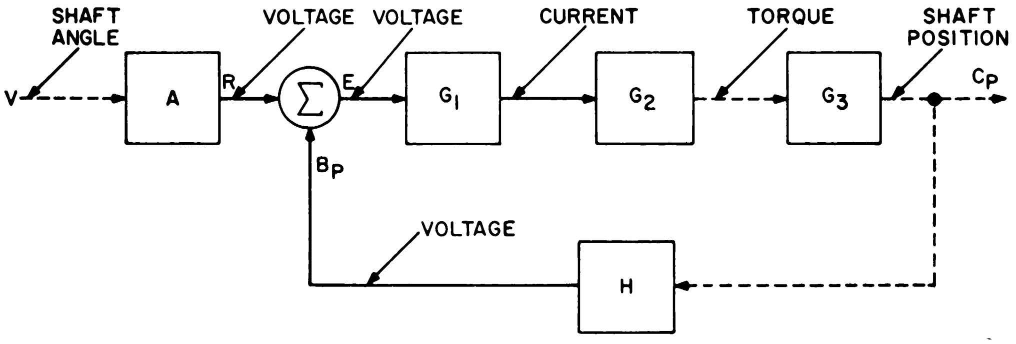

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Figure 9-12. — Block diagram of position servo.

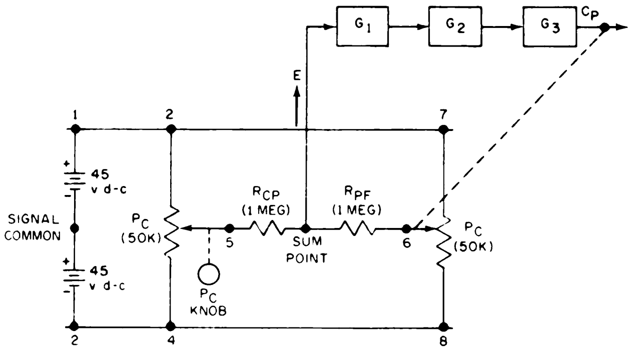

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Figure 9-13.—Position servo showing "A" and "H" blocks in schematic form.

by the polarity of the applied voltage. The polarity in one instance will cause clockwise shaft rotation and, when reversed, will cause counter-clockwise shaft rotation.

Figure 9-13 is a hybrid illustration, showing the gain elements as block diagrams and the error section in schematic form to help explain the system's operation. Certain points in the schematic portion are numbered and the signal common and the sum point identified only for explanation reference points. The schematic shows two 45-volt batteries as the reference power supply. P_c is a manual command potentiometer whose knob would position the wiper arm, and R_{cp} is a one megohm summing resistor. These two components are the input variable signal transducers which are represented by the "A" block in the preceding diagram. P_f is another potentiometer whose wiper arm is mechanically connected to the gearing shaft output (denoted by the dotted line) and R_{fp} another one megohm resistor. These two components are the response signal transducers which are represented by the "H" block in the preceding diagram.

Now assume the "G" blocks are properly mechanized for operation and the system is still motionless. Why? As movement or positioning depends upon an error signal having a value other than zero. If the error signal is zero, the system is in a steady state of equilibrium, or null position. With the wiper arms of P_c and P_f at the mid point of travel, a voltage measurement from signal common to point 5 or 6 would be zero. Therefore, zero volts would also be measured at the sum point which means the value of (E) is zero. With no input signal the amplifier output is zero. With no amplifier output the motor is standing still.

Assume for a moment, that the line between G_1 and G_2 is open, so the motor will not operate in any event. Now, imagine the P_c wiper arm is manually moved upward to a new position where a voltage measurement from a signal common to point (5) would measure +10 volts. Further measurements would show zero volts between signal common and point (6), but +5 volts between signal common and the sum point. This +5 volts is "E" the error signal and it would be amplified and drive the motor clockwise if the G_1 — G_2 line were closed. Before closing the G line, first examine how the error voltage was developed. The +10 volts, measured at point (5) was achieved because the P_c wiper arm was moved up 10 volts from signal common. Moving over to the sum point, 5 volts is measured; and at point (6), zero volts. The drop in voltage is due to the IR drop across the summing resistors R_{cp} and R_{fp}.

Applying Ohm's law, solve for the IR voltage drop across R_{cp}.

1. First, the current in the circuit must be determined. Trace the current path from point 2 across to point 8, up P_f to the wiper arm point 6, across R_{fp} to the sum point, across the R_{cp} to the P_c wiper arm point 5, up P_c to the positive side of the line at point 3. Neglecting the resistance of P_c and P_f, which are very small compared to the summing resistors, the circuit resistance is 2 megohms.

Therefore:

I = E/R or 10 volts/2 megohms

I = 5 microamperes

2. Now that the circuit current is known, the voltage drop across R_{cp} can be determined:

E = I times R or 5 microamperes x 1 megohm

E = 5 volts drop across R_{cp}

3. The drop across R_{cp} and R_{fp} is:

E = I times R or 5 microamperes x 2 meghoms

E = 10 volts drop across R_{cp} and R_{fp}

Assuming the $G_1 - G2$ line is now closed, the instantaneous error signal input of +5 volts into G_1 is amplified, and the amplified output starts driving the motor and gearing. The output shaft will drive the load toward its new position.

Cancellation of an error signal by increasing the current flow through R_{cp} and R_{fp} is easily understood if you think of the circuit being in a "null" condition (no error signal) when the sum point is 45 volts positive in respect to points 2 (4 and 8). This is actually the situation shown, and if you measured from points 2 (4 and 8) to either the signal common or sum point you would read 45 volts positive.

When the output shaft turns, the P_f wiper arm is turned by the mechanical coupling. As soon as the wiper arm is turned, the voltage it picks off begins decreasing. Thus, if the reference voltage (signal common) is considered as being 45 volts positive in respect to point 2, the P_f wiper (point 6) is moved in a negative direction, or toward point 8, and measures 40 volts positive in respect to point 2 (4 and 8). The response signal (B_p) is therefore negative with respect to the input signal (R). The proper polarity relation can be determined analytically if component data is available, or by observing that the coupling drives the wiper arm of P_f in the direction opposite the movement of the P_c wiper arm.

With the voltage decreasing at the P_f wiper arm (point 6), the +5 volts error signal decreases in value. To see this more clearly, suppose the voltage from signal common to point (6) is being measured. The voltage being measured is going negative. The input signal variable (P_c wiper arm position) is not changing, so when the P_f wiper is at +40 volts (in respect to point 8) the error signal is reduced as follows:

1. The voltage difference between point (5) and (6) is now 15 volts, so the current through R_{cp} and R_{fp} is:

I = E/R or 15 volts/2 megohms

Therefore:

I = 7.5 microamperes

2. The IR voltage drop across R_{cp} is

E = I times R or 7.5 microamperes x 1 megohm

E = 7.5 volts drop across R_{cp} so the voltage at the sum point (error signal) is now 2.5 volts.

When the P_f voltage reaches -10 volts, the error signal voltage will have been reduced to zero and the system then stops at its new position. This new position is the null position, which is descriptive of a servo being in a state of equilibrium, regardless of its position.

Error signal generation is the basic foundation of any servosystem.

VELOCITY SERVO OPERATION

The velocity servo, while based on the same principle of error signal generation, differs from the position servo in operation in a number of ways. Two of the major differences are:

1. The output variable element of interest is velocity instead of position.
2. In operation and null, an error signal is always present.

The velocity servo is used in applications where the controlled output variable drives a load device at a constant speed, which is established by the level of the error signal present. The types of load it might drive include radar antennas, shafts, star tracking telescopes, machine cutting tools or any device requiring variable speed regulation.

Figure 9-14 is a block diagram of a velocity servo. Although similar to the position servo, the shaft output is noted sub v, indicating that velocity is the element of interest. Also, the response signal B is noted sub v, indicating it is a velocity related signal.

In the hybrid illustration of figure 9-15, the gain blocks are shown in block diagram form and the error signal generating section is shown schematically. The power supply and reference points are shown for explanation purposes. The velocity servo employs the same reference transducers. P_c command potentiometer and R_{cp} summing resistor as were used in the position servo. The response transducers however, are changed to a tachometer (d.c. generator) and a 3 megohm summing resistor, R_{fv}. The tachometer shaft is mechanically coupled to the G_2 (motor) output. The tachometer

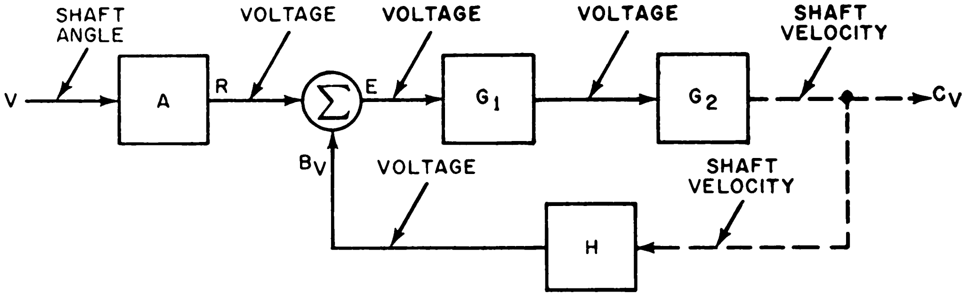

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Figure 9-14.—Block diagram of velocity servo.

generates a voltage proportional to speed, in this case, the transfer function is 1 volt/200 RPM. The polarity depends on the direction of shaft rotation.

The "G" blocks are assumed properly mechanized and the motor is again a 12-volt d.c. permanent magnet motor. The combined transfer function of the G_1 and G_2 blocks will be assumed to be 1000 RPM (C_V)/volt (E). The system is not operating because no input signal is present since the P_c wiper arm is at zero volts (signal common to point 5) and the tachometer is not turning, so no error signal is present.

Now imagine, while measuring the voltage from signal common to point (5), that the P_c wiper arm is manually moved downward until the voltage measurement is -10 volts. The error signal, instantaneously, becomes -7.5 volts. Why? The tachometer output was at zero, so the current (neglecting P_c and the internal tachometer resistance) through the summing circuit is 2.5 microamperes (I = 10/4 megohms). Therefore the drop across R_{cp} is 2.5 volts (E = 2.5 microamperes x 1 megohm). The voltage at the sum point must then be -7.5 volts (measured from signal common across R_{fv} and d-c tachometer) and is the error signal (E).

With a -7.5 volt error signal as the input to G_1, the motor begins to turn counterclockwise.

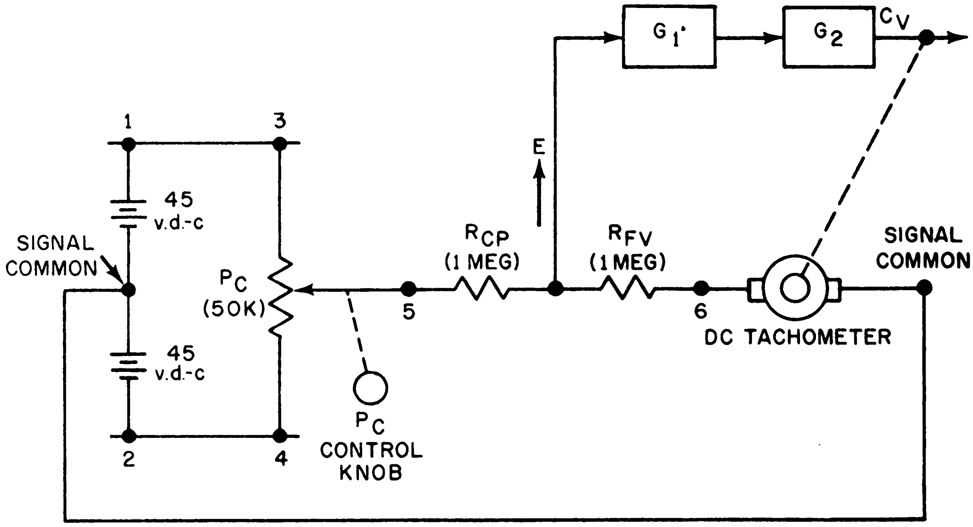

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Figure 9-15.—Velocity servo with "A" and "H" blocks in schematic form.

The transfer function between (C_V) and (E) was stated as 1000 RPM/volt, which means the motor will accelerate to 7500 RPM if (E) maintains this level. However, the motor is coupled to the tachometer, so as soon as the motor starts turning, the tachometer begins to develop a voltage of the sign opposite the input. (The tachometer polarity was determined by the way the tachometer leads are connected in the error signal generation section).

When the motor velocity and tachometer reaches 3000 RPM, what is the error signal? It was stated before that tachometer develops 1 volt per 200 RPM, so the tach output at 3000 RPM is +15 volts. The P_C voltage is -10 volts. The comparator circuit current, again neglecting the relatively low P_C and tachometer resistance, is 6.25 microamperes and the IR drop across R_{CP} is 6.25 volts. The voltage at the sum point, which is the error signal (E), is now -3.75 volts. The motor is still increasing in speed but now towards a new target of 3750 RPM.

When the motor speed reaches 3333 RPM the tach output is +16.66 volts. What is the error signal (E)? The circuit current is found to be 6.666 microamperes and the error signal is reduced to 3.33 volts. The motor speed is 1000 RPM per volt of error signal, so unless the error signal increases, the motor can go no faster. The only way to increase the error signal would be to further increase the input variable signal, in which case the system would speed up to the new point of equilibrium between motor speed and error signal.

The equilibrium is the velocity null and an error signal is always present but remains steady in the velocity null state. While the system is following a command to increase or decrease speed, the error signal (E) is changing in value.

ACCELERATION SERVO

The acceleration servo is based on the same basic principles as the position and velocity servos. Its output variable (C) is acceleration (rate of change of velocity) or (C_a). The response transducer which measures the controlled variable is an accelerometer and the response signal B_a is a signal related to the acceleration of the output.

The "accelerometer" may not be an accelerometer in the true sense of the word. To understand what we mean by this, consider, once again, the output of the tachometer in the velocity servo. The tach output changed from zero volts to +16.66 volts over a period of time. Therefore, the rate of change of the tach output is indicative of the acceleration. There are methods of determining this rate of change and using it to affect the response so as to aid the acceleration of the output. In other words, the response signal will assist the input signal in overcoming the inertia of the load. As the output is accelerated to its new velocity, the affect on the response diminishes until once again a null or state of equilibrium exists between input signal and response. More will be said concerning this when we consider the operational characteristics of servosystems, which is the next subject of interest.

SERVO CHARACTERISTICS

The operational characteristics of a servo are determined primarily by its job. There are just about as many different types of servos as there are jobs for servos to do. Generally speaking, a servo has a common purpose — to control its output in a manner dictated by its input. Ideally, the motion and position of the output shaft should duplicate the motion and position of the input shaft. But we never get ideal performance from servos. We will discuss the major reasons for this, and show some of the approaches taken to improve servo performance.

There is always a time lag between a change in the input signal and the servo's reaction to the change. Any physical motion requires time. In addition, the error signal must have sufficient magnitude to cause the servo to drive. Below this level the servo is insensitive to signal change. The servo's time lag will be decreased, and its sensitivity to small signal changes increased, by an increase in the gain of the amplifier. But if the gain is set too high the servo output will tend to oscillate, and to be unstable. Hence the gain of a servo is limited by stability considerations. The sensitivity of a servo is counterbalanced against its stability to obtain the best operation.

All signals in a servo except for the response signal are considered to originate outside the amplifier. Input signals to a servo always contain some roughness, such as noise in an electrical signal. This roughness must be eliminated to obtain smooth operation. Let's consider a director train power drive with a position signal from a CX — CT synchrosystem. There are physical limits to the rapidity of the director's movements. Slow variations in position must be accepted as possible director motion, but rapid fluctuations in the signal may be rejected as being impossible for the director to achieve. Thus by an examination of the signal's frequency spectrum we can detect and eliminate known noise frequencies. Filters in the signal circuit can shunt noise frequencies away from the amplifier, and allow only those frequencies that represent director motion to enter the amplifier.

If the capabilities of a servo's load are known, we can attenuate or eliminate some of the unwanted frequencies in the signal. In other words, a bandwidth for the servoamplifier is established. The bandwidth must include all the frequencies that could represent valid signals. Hence frequencies which are actually caused by noise but could represent valid motions of the signal must be accepted. Damping and stability feedback are used to reduce this roughness in the servo. We will cover damping separately, later in the chapter.

An increase in bandwidth causes a corresponding increase in noise generated in the amplifier, and a loss in gain. The response signal fed back to the error detector is proportional to the amplifier's output and contains any noise generated there. Since response is 180° out of phase with the input signal, it is a negative feedback. Consequently the advantages of negative feedback are applicable to servos. One of these advantages is that nonlinear distortions and noises generated in the amplifier are reduced by response. This does not eliminate noise in the error signal input to the amplifier.

Response in a servo tends to make the overall gain of the amplifier independent of variations in load, supply voltages, and aging of the tubes. This gives the amplifier a constant gain factor and the servo a flat amplitude response curve. A constant gain factor will provide a linear relationship between the input and output signals of the amplifier throughout its operating limits. Therefore an error signal of a given amplitude will produce an output signal with a definite amplitude. The amplifier's output is, of course, the control signal to the error reducer. Hence if the error reducer has a linear relationship between control voltage and torque produced, the servo's response will be directly proportional to the error signal.

Variations in the gain of a servo are sometimes desirable to compensate for load variations. Consider the director train servo we spoke of before. The director has mass, and therefore has inertia. Inertia is the property of a body which resists changes in motion. A change in motion is an acceleration and a force is required to accomplish acceleration. Since the director has inertia, a larger force is necessary to start the director into motion or to accelerate the director's motion than the force required to maintain the director at a constant velocity.

Assume the director is tracking a target which causes the director to train at a constant velocity to the right. Now assume that the target changes course, requiring the director to reverse its direction and train to the left. To do this the train servo must first stop the director's movement to the right. Since the director has inertia, there is a sudden increase in the load on the servo as it attempts to stop the director. The error signal to the servoamplifier does not reflect this increase in the load due to inertia. Hence there is a time lag before the director is stopped and started to the left. The time lag can be reduced if the gain of the amplifier is varied to compensate for load variations.

The load's variation is due to acceleration. Thus a signal proportional to a change in the load's velocity could be used to vary the amplifier's gain. The velocity feedback signal would originate at the load from a source such as a rate generator.

The amplifier's gain is sometimes varied by the amplitude of the error signal. When there is a large displacement between the load position and the ordered position we would want the servo to accelerate rapidly to its maximum velocity and to maintain that velocity until the load is close to the ordered position. The error signal to the amplifier could be used to shift circuits in the amplifier to vary its gain. When the error signal's amplitude reached a preset level it would automatically shift the gain.

SERVO CIRCUITS

In this section of the chapter we will discuss the circuits and the components that make up a servo. It is not practical to cover all their applications in fire control servos. Therefore, we have divided the circuits by their function and have selected applications that will teach the different methods of accomplishing the function. We will not cover the material presented in the basic texts (Basic Electricity, NAVPERS 10086-B and Basic Electronics, NAVPERS 10087-C). Therefore, it probably will be necessary for you to read the basic texts before you study the material presented here. We will cover the application of vacuum tubes, transistors, and magnetic circuits plus the use of amplifiers, motors, and generators without discussing the theory of operation of these units. Like an iceberg, most of the material necessary to understand servos is below the surface in the basic theory.

SENSING ELEMENTS

This section deals with devices that measure, convert, or sense the INPUT and OUTPUT of any servo, and express them in suitable form. The more common types of these devices convert motion into corresponding electrical energy. These devices are part of the class called transducers. This book will not attempt to put the units treated here into any rigid classification system. Instead, some of the more common terms used by manufacturers and the Navy to classify these devices are mentioned so that you can become familiar with a wide variety of nomenclature.

Potentiometers

In servos the input information is usually in the form of a voltage or shaft position. The error signal to the servoamplifier is normally an electrical signal. The response may be a voltage or a mechanical quantity. You can see that some energy-converting device is required in almost any servo, as well as a device which measures position of the input and output. A potentiometer is one of the simplest means of accomplishing these functions. You have already studied potentiometers used as transducers when you studied the preceding sections of this chapter which covered position and velocity servo operation.

Variable Transformers

A variable transformer is a device in which the magnetic coupling (primary and secondary) between a set of stator coils and a set of rotor poles (which may or may not be wound) can be varied by moving either the rotor shaft, the stator assembly, or both. Variable transformers, like the other devices mentioned here, may be classified by many different methods. A few of these are: (1) application, (2) construction, (3) principles of operation, and (4) manufacturers' trade names.

These devices may be used in servosystems to perform many functions. They are used to transmit information between remote units of a system. Some examples of data transmission units are synchros, resolvers, E-transformers, and the microsyn.

Although synchros and resolvers are familiar subjects, they will be presented in greater detail in forthcoming sections of this training manual. E-transformers and microsyns may be new to you. They find extensive use in conjunction with gyroscopes. Therefore, they will be covered in the next chapter.

SYNCHRONIZING CIRCUITS

Use of a dual-speed synchro transmission system increases the accuracy of the servo. But a dual-speed synchro system introduces a problem—how can a servoamplifier tell when it is, or should be, receiving a fine or a coarse signal? Most synchro systems transmit at one or more of the following speeds: 1X, 2X, 18X, 36X, and 72X. A typical dual-speed synchro control system, such as for bearing data transmission, has a coarse CT (control transformer) at 1-speed, and a fine CT at 36-speed. In this system, response from the servo to the fine CT is driven at 36-speed and each rotation of the shaft represents 10 degrees. Therefore, if the error is large, the servo could synchronize at a false point. To prevent this, control of the servo must be shifted to the coarse CT when the servo is more than two or three degrees out of synchronization.

A synchronizing circuit is included in the servo to sense how far the load is from the ordered position and then to switch the appropriate signal into control. The signal selected by the circuit is the input to the amplifier. The selection is based on the size of the error signals the circuit receives. The coarse signal is the predominant factor in the selection, since it is a measure of the servo's output position throughout its limit of motion. The coarse signal drives the system into approximate synchronization, where the fine signal is shifted into control. The servo is normally controlled by the fine CT, the coarse CT has control only when the servo is far out of synchronism.

Relay-Operated Synchronizing Circuit

The relay circuit (fig. 9-16) connects the fine or the coarse CT to the amplifier. One side of both error signals is connected to the fixed contacts of relay K1. The other side of each error

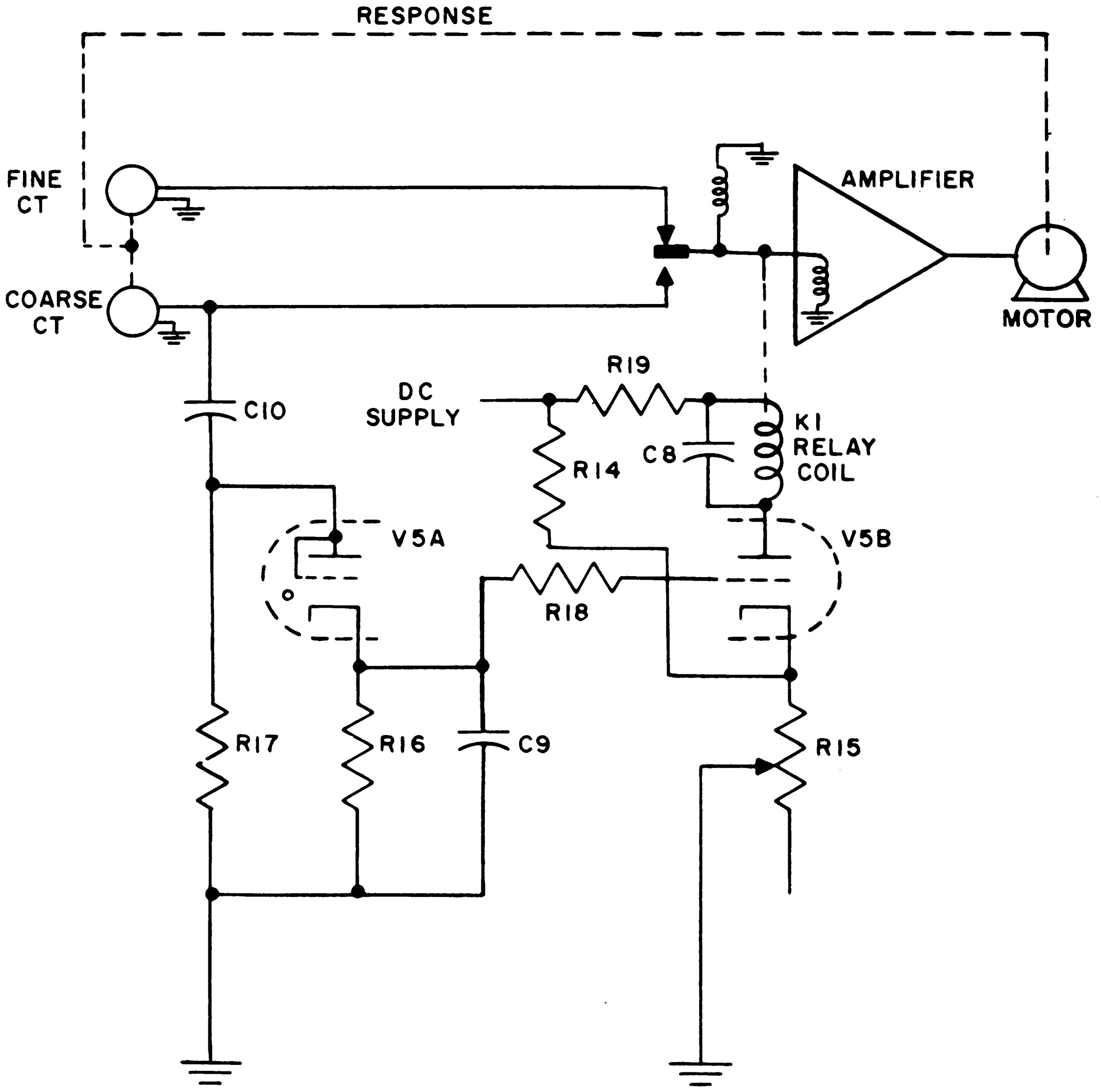

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Figure 9-16.—Relay operated synchronizing circuit.

signals is grounded and thus is common. The movable contact of K1 is spring loaded so that it normally makes connection with the fine signal contact. Therefore, when K1 is deenergized the fine signal is passed to the amplifier, and conversely when K1 is energized the coarse signal has control. Hence, the coarse signal is used to control the d-c supply to the coil of K1.

The coarse signal is applied to the plate of V5A. The plate and grid of V5A are tied together and the tube operates as a diode, half-wave rectifier. When the plate is positive, it will conduct. The output from V5A is a pulsating d-c voltage taken from the top of R16, the cathode resistor. Thus V5A rectifies the coarse signal.

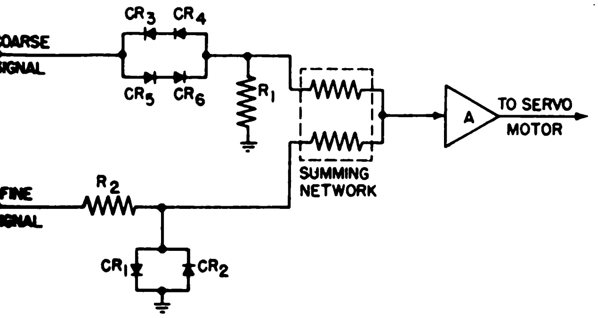
Tube V5B is in series with the coil of K1. V5B is biased below cutoff by the cathode resistor, R15. The grid potential varies with magnitude of the rectified coarse signal from V5A. If the grid signal exceeds a fixed value, V5B will conduct. When this occurs current flows in the plate ircuit and energizes K1. The relay will pick p and shift control to the coarse error signal.

The circuit for K1 is from ground through 15 and V5B, then through the coil of K1 and 19 to the positive side of the DC supply. Since the ignal to the grid of V5B is a pulsating d-c oltage, the tube's conduction will pulsate which ill cause the relay to chatter. C8 is placed cross the coil of K1 to reduce the chatter of e relay. R19 is a voltage-dropping resistor series with the relay coil. R14 and R15 orm a voltage divider circuit. R15 is adjustable nd controls the cathode bias of V5A.

R15 is adjusted so that V5B will conduct and 1 will pick up when the sine of the coarse error ignal is the proper value. Normally this will ccur when the servo is from two to three egrees out of synchronism. The exact value of rror signal will depend on the characteristics f the servo. Generally speaking, we want the ne CT in control of the servo as long as posible. For a small displacement the fine error ignal is much larger and provides a much tighter ontrol of the servo. But if too large a coarse rror signal is needed to pick up K1, we risk e possibility of a false synchronization or the ervo oscillating about the synchronization point s the fine and coarse CTs buck each other.

emiconductor Diode ynchronizing Network

The semiconductor diode synchronizing netork is fairly common, so let's take a look at nother circuit using this technique. This circuit illustrated in figure 9-17. Within a range of pproximately 3° on either side of the synchroizing point, the coarse signal is effectively blocked because of the high impedance of the series diodes, CR3, CR4, CR5, and CR6. With the coarse signal blocked, the fine signal is fed into the summing network and is in control of the servo. However, this signal is limited to a very low voltage by the parallel diodes, CR1, and CR2.



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igure 9-17.—Semiconductor diode synchronizing network.

Both the fine and coarse voltage inputs will increase as the error in correspondence is increased. CR1 and CR2 develop the fine signal. A point will be reached (about 3° error) when CR1 and CR2 will be incapable of dropping a greater voltage.

Now let us look at the coarse signal. In figure 9-17 you will notice that the coarse signal is developed across R1. Also notice that the diode network of CR3, CR4, CR5, and CR6 is in series with R1. Errors in correspondence which are less than 3° will cause some current to flow through R1 and the diode network. However, this current is small and will cause the diode network's resistance to be high. Therefore most of the coarse signal voltage is dropped across the diode network and very little voltage is developed by R1. In this condition the resultant voltage in the summing network is predominantly from the fine synchro. As we get further out of synchro correspondence, the current through the coarse signal diode will increase causing a decrease in the diode network's resistance. A smaller percentage of voltage will be dropped across the diode network and thus more signal voltage developed across R1. Circuit resistance is selected so that the voltage developed across R1 (coarse signal) will override the voltage across CR1 and CR2 (fine signal) when the synchro correspondence error is 3° or more. The coarse signal now has control of the servo. When the servo error becomes less than 3°, the fine signal resumes control.

In similar circuits, zener diodes are used in place of the selenium or crystal rectifiers. When the voltage across a zener diode reaches the zener voltage (breakdown voltage), the current flow through the diode increases very rapidly while the voltage drop across the diode remains almost constant. (Zener diodes are covered in Basic Electronics, NavEdTra 10087-C.) Therefore, when the coarse error signal is sufficiently large the voltage will break down the zener diode's internal barrier. The large current flow means the signal will pass through the diode with a minimum of loss.

MODULATORS

Some servos have a d.c. error voltage and an a.c. amplifier or motor. Consequently, the d.c. error voltage must be converted to an a.c. voltage that contains the same data, the direction and magnitude of the error, before it can be used. The circuit that converts the signal from d.c. to an a.c. voltage is called a modulator. Modulation is the process by which the amplitude, frequency, or phase of a carrier wave is varied with time in accordance with the wave form of a superimposed intelligence. Modulation and demodulation are covered in Basic Electronics, NavEdTra 10087-C.

In the modulator circuit the carrier wave is the servo's a.c. reference voltage. The superimposed intelligence is the d.c. error signal. The polarity of the d.c. error voltage indicates the direction of the error, and its magnitude is proportional to the amount of error. Therefore, the phase of the a.c. signal is related to the polarity of the d.c. signal, and the magnitude of the a.c. signal is proportional to the d.c. signal voltage.

The modulator circuits use elements that act as synchronous switches. Examples of these elements are: transistors, crystal or metallic rectifiers, diodes, triodes, and mechanical contactors. The elements have a high front-to-back resistance ratio, so that current will flow through the "switch" only in one direction. The switches are operated at the carrier frequency, which is usually 60 or 400 Hertz. The resulting pulsating voltage is proportional to the d.c. error voltage. The phase of the pulsation voltage is determined by the polarity of the d.c. error signal.

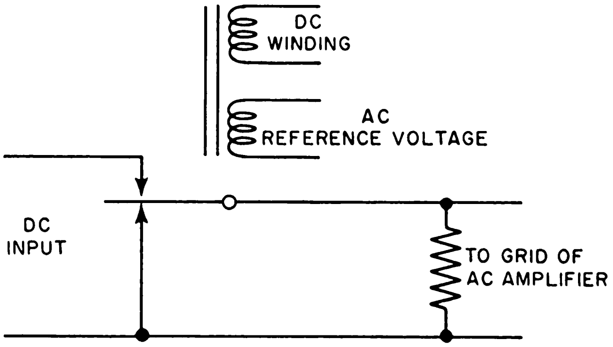

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Figure 9-18. — Electromechanical vibrator (chopper).

Vibrator Modulators

A modulator may be either an electromechanical or an electronic circuit. An example of an electromechanical circuit, called a vibrator or chopper, is shown in figure 9-18. The coil is energized by alternating current at the appropriate frequency, usually 60 or 400 Hertz.

To prevent the vibrating arm from being attracted twice by the coil during each cycle, some direct current is passed through the coil, or through another coil wound on the same core. Thus when the alternating current flows in the other direction, its magnetizing force is canceled by that of the direct current, and the attraction on the arm is reduced. The arm thus vibrates at the frequency of the a.c. supply (reference) voltage. Most choppers use a permanent magnet in place of the d.c. winding.

To reduce the power required to drive the arm, the arm is usually tuned so that it vibrates naturally at the proper frequency. The output is then a square wave, having the level of the d.c. input for one-half cycle and zero level for the other half.

Blocking condensers in the amplifier that follows the chopper remove the d.c. components, so that the signal becomes a square wave with [illegible] amplitude proportional to the d.c. signal level and a phase which reverses when the d.c. signal changes polarity. This amplifier also discriminates against high frequency signals, so that the square wave ultimately is converted to [illegible] sine wave at the frequency of the vibrator switching.

If the motion of the vibrator arm is synchronized so that the contacts make and break [illegible] phase with the reference a.c. voltage, the vibrator's output voltage will be in phase with [illegible] reference voltage. In some applications a phase shift is introduced by the vibrator. The vibrator arm is synchronized one-quarter cycle after [illegible] peak of the a.c. reference voltage. Thus the vibrator output will lag the reference voltage by [illegible] degrees. The error signal entering the amplifier contains the 90-degree phase shift necessary [illegible] start or stop a split-phase servomotor.

In some servos a vibrator is not only used to change d.c. to a.c., but is also used as a subtraction device. Suppose the vibrator input terminals were supplied with two signals, one equ

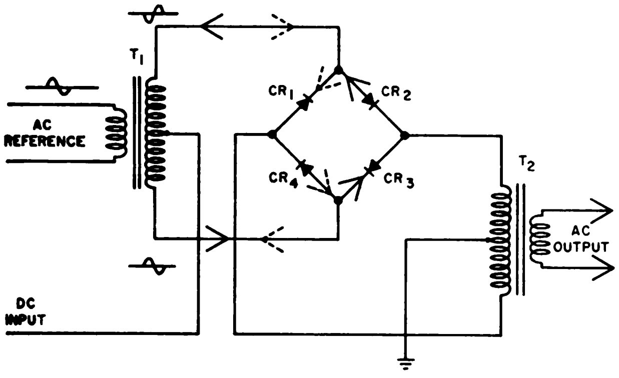

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Figure 9-19.—Crystal diode modulator.

o plus five volts and the other equal to minus ive volts. The vibrating contact will move beween the two points, which differ in potential y ten volts. The output of the vibrator is proortional to the difference in potential between he vibrator's inputs. In this example, the circuit utput would be a square wave with an amplitude f ten volts peak to peak. Recall that a servo's rror detector will measure the voltage difference etween the ordered signal and the response ignal. This is exactly what the vibrator is doing.

rystal Diode Modulator

The crystal diode modulator (fig. 9-19) conists of a diode bridge and transformer network. Vhen a reference voltage is applied to transormer T1, diodes CR2 and CR3 conduct during the egative alternation of the reference voltage. There is a 180° phase reversal in T1.) Conersely, diodes CR1 and CR4 conduct on the ositive half-cycle of the reference voltage. lectron flow during the positive and negative lternations is represented by dotted arrows and olid arrows, respectively. If a positive d.c. ignal voltage is applied during the negativeoing alternation, electrons will flow from round, through the upper half of the primary inding of transformer T2, through diode CR2 and hrough the upper half of the secondary winding f transformer T1 to the d.c. source. Curent flow through the bottom of T2, CR4, and he bottom of T1 secondary is opposed by the pposite polarity across CR4. On the positiveoing alternation, electrons will flow from round, through the lower half of the primary of transformer T2, through diode CR4, and through transformer T1 to the d.c. signal source.

If a negative d.c. signal is applied, electron flow through the circuit will be reversed. That is, electrons will flow from the d.c. signal source, through diodes CR3 and CR1 in turn, to ground. Since, in all cases electrons are caused to flow through the primary of transformer T1 at the rate of the reference voltage, the output of this transformer will be at the frequency of the reference voltage. The phase of the a.c. output signal is determined at any given instant by both polarity of the d.c. input and the phase of the a.c. reference voltage.

Electron Tube Modulators

An example of an electronic modulator is shown in figure 9-20. The input d-c error voltage is impressed between E1 and ground. The a-c reference voltage along with the action of V1, V2, R2, and R3 effectively clamp output E2 at zero potential for one-half cycle of the reference voltage. To accomplish this, the following conditions must exist:

1. R1 must be much larger than R2.
2. R2 and R3 are equal.
3. V1 and V2 must be matched (usually a balance circuit is included to match the tubes).

With a reference voltage applied, making the plate of V2 positive and the cathode of V1 negative, current will flow through V1, R2, R3, and V2. Since R2 equals R3, voltage E3 will equal E4.

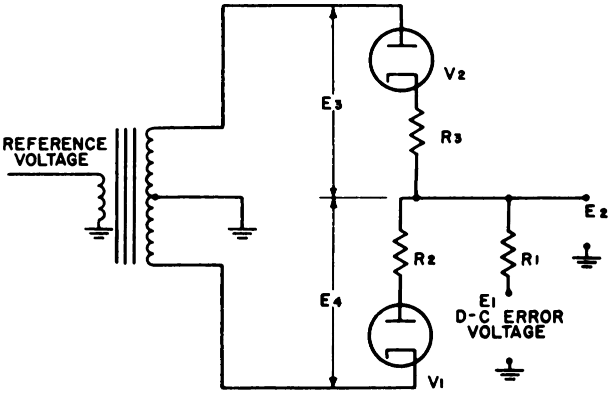

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Figure 9-20.—Electronic modulator.

If the d.c. error voltage is positive, V1 will pass current down across R1, effectively dropping the amount of the error signal. The voltage output at E2 for this half cycle will be zero. If the d.c. error voltage is negative, current will pass up across R1, R3, and through V2 to the source. R1 once again (because of its size) drops an amount almost equal to the d.c. error voltage and the signal at E2 will again be almost zero.

We can readily see that when the tubes conduct, the voltage at E2 will be almost zero, and when they are cut off by the reverse polarity of the reference voltage, the output voltage will be equal to the d.c. error input. This will result in a pulsating d.c. output with its amplitude and phase determined by the amplitude and polarity of the d.c. error voltage.

DEMODULATION

Some fire control servos use d.c. servomotors to drive the load. A typical example is the amplidyne power drive. Amplidyne power drives are covered in Basic Electricity, NavEdTra 10086-B. The input signal to an amplidyne servo is usually an a.c. synchro voltage. This requires that the a.c. order signal be converted to a d.c. signal. To accomplish this a demodulator circuit is used. Demodulation is the process of extracting the signal intelligence from a modulated carrier wave. In the amplidyne type servo the modulated carrier wave is the a.c. signal from the CTs. The magnitude of the a.c. signal is proportional to the size of the error and the phase of the intelligence we must extract.

To derive a d.c. signal having the same intelligence as the a.c. signal we must be able to detect both the phase and the magnitude of the a.c. signal. The polarity of the d.c. signal is determined by the phase of the a.c. signal compared to a reference voltage. The reference voltage must be from the same source as the synchro supply, which is the voltage we modulated in the first place. The magnitude of the d.c. signal is directly proportional to that of the a.c. signal.

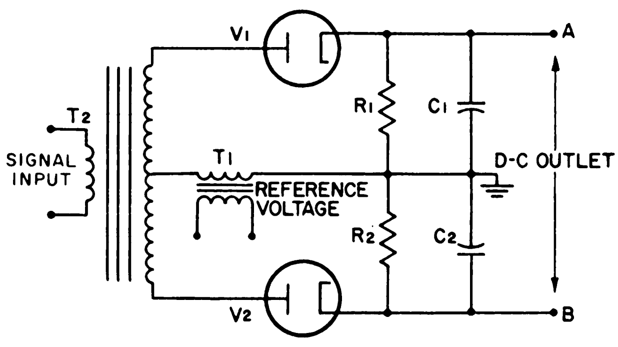

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Figure 9-21.—Diode vacuum tube demodulator.

Demodulators are often referred to as phase-sensitive rectifiers or detectors, phase-discrimination converters, or simply as discriminators and detectors. These are high-sounding names for, as you will see, a circuit with which you are fairly familiar. If you understand the operating principles of modulators, demodulators will be easy for you to learn.

Diode Demodulators

A typical diode demodulator (phase detector) is shown in figure 9-21. As illustrated, an a-c supply voltage serves as the reference voltage for the detector. This voltage must come from the same source that is supply a.c. excitation to the synchro system, or whatever type of error detector is used, and must be in phase with the common supply voltage. This permits a phase-comparison of the error voltage with the reference voltage. The plates of the two diodes are supplied with this reference voltage in such a manner that the two plates will be in phase. Assuming that there is no error signal from T2 to the plates of the diodes at the time the plates are on a positive half-cycle, the two diodes will conduct equally. The voltages produced across R1 and R2 are equal, making the cathode of V1 and V2 at equal potential with respect to ground. With the two output terminals at the same potential, the output voltage will remain at zero as long as no error signal is applied.

If an error signal is applied to T2 making the plate of V1 positive at the same time the reference voltage on the plates of V1 and V2 is on its positive half-cycle, V1 conduction will be increased and V2 conduction decreased over the no-signal condition. Since the voltages applied to the plates are both alternating, the voltage developed across R1 and R2 would also be alternating. However, R1-C1 and R2-C2 have a long time constant compared to the input frequency, and therefore filter most of the ripple, giving a d.c. output.

If the error signal applied to T2 is changed by 180 degrees, V2 would now increase its conduction while the conduction of V1 would be reduced. This would result in an output voltage of

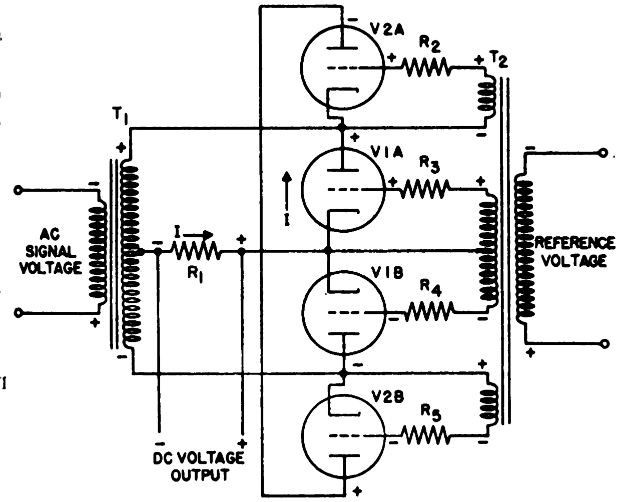

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Figure 9-22.—Triode demodulator.

reversed polarity. Variations of the diode phase detector may be encountered; however, they all depend on the same basic principles of operation.

Triode Demodulator

The demodulator shown in figure 9-22 is a full-wave phase-sensitive demodulator. It compares an a.c. signal voltage with an a.c. reference voltage to produce a d.c. output. In this circuit there are two sets of conditions for the polarities of the input voltages, since at any instant of time the reference voltage and the signal voltage will be in phase or 180° out of phase.

An in-phase condition is shown in figure 9-22. An examination of the existing instantaneous polarities reveals that only V1 can conduct. Each section of V1 will conduct on alternate half-cycles of input voltages. This is approximately the action of a full-wave rectifier.

Consider the instantaneous polarities present:

1. V2A is not conducting because its plate is negative.
2. V2B is not conducting because of the negative bias on its grid; the windings of T2 bias it below cutoff.
3. V1B is not conducting because its plate is negative.
4. V1A is conducting because both plate and grid are positive with respect to the cathode. The current, I, will flow through the tube and resistor R1 as shown, producing the output d.c. voltage across R1.

On the alternate half-cycle of the a.c. voltages, V1B will conduct and the d.c. current through R1 will be in the same direction as before.

For the reverse condition, when the a.c. voltages are 180° out of phase, V2 will conduct. The d.c. output voltage across R1 will reverse its polarity.

Electric Demodulator

The demodulator shown in figure 9-23 will rectify an a.c. signal and convert it to a pulsating d.c. signal proportional in magnitude to the input

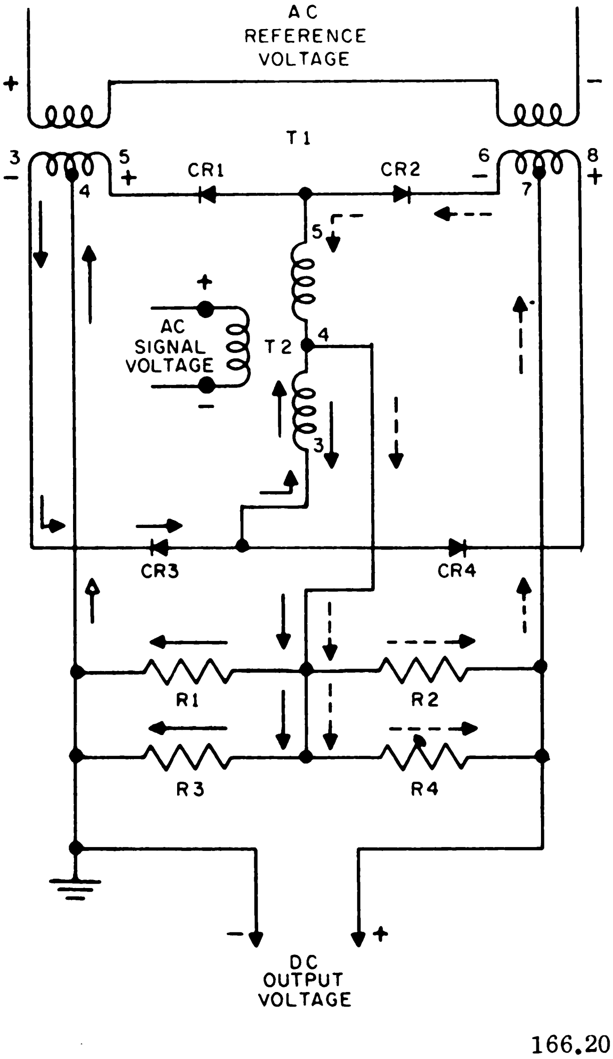

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Figure 9-23.—Electric demodulator.

signal voltage. The polarity of the d.c. output voltage is determined by the phase of the signal compared to the reference voltage. Naturally, the signal and reference voltages are of the same frequency.

We will assume that the signal voltage on transformer T2 is in phase with the reference voltage on transformer T1. In the half cycle shown the current depicted by the dotted arrows starts at terminal 6 of T1, flows through the rectifier CR2, winding 5-4 of T2, and parallel resistors R2 and R4, to terminal 7 of T1. The signal and reference voltages in these secondary windings of the transformers are in additive series. Therefore, the voltage across the parallel resistors is proportional to their sum.

The current depicted by the solid arrows starts at terminal 3 of T1, flows through rectifier CR3, winding 3-4 of T2, and parallel resistors R1 and R3, to terminal 4 of T1. The voltages in both these transformer windings are in subtractive series. Therefore, the voltage across the resistors is proportional to their difference.

Consequently, the voltage across resistors R1 and R3 is smaller than the voltage across the resistors R2 and R4. The resultant voltage across the resistor network and at the output terminals is the algebraic sum of the two voltages. The polarity of the output voltage is the same as that of the greater voltage.

On the next half cycle the signal and reference voltages are still in phase. You should be able to trace the current flow in the demodulator mentally without a bunch of arrows. We will start at terminal 5 of T1 which is now negative, through CR1, winding 5-4 of T2, and parallel resistors R1 and R3, to terminal 4 of T1, which is now positive with respect to terminal 5. The voltages are still in subtractive series.

In the other pair of windings we will start at terminal 8 of T1, which is now negative. From terminal 8, the current flows through CR4, winding 3-4 of T2, and the resistors R2 and R4, to terminal 7 of T1, which is now positive with respect to terminal 8. The voltages in the secondary windings of T1 and T2 are still in additive series. Hence the voltage across the resistor network is the same for both half cycles and the output from the demodulator is a pulsating d.c. voltage.

If we assume the signal voltage is 180 degrees out of phase with the reference voltage the direction of the current flow through the resistor network would be reversed. The voltage across R1 and R3 would now be larger than the voltage across R2 and R4. Therefore, the polarity of the output voltage would be reversed.

The peak-to-peak value of the reference voltage is constant; therefore, the magnitude of the output is determined by the size of the error signal. With no signal present the reference voltage drop across the resistor networks would be equal and opposite, and there would be no output. This balance is disturbed by the error signal.

SERVOAMPLIFIERS

Servoamplifiers have several inherent advantages:

1. Flat amplitude response or gain over the broad band of frequencies of interest.
2. Small and fixed phase-shift of the output with respect to the input.
3. Low output impedance, and low nonlinearity of amplifiers.
4. Low noise level.

It is not practical to discuss individual amplifiers in this text. But we have selected representative amplifiers to indicate the various functions they perform in a servo. This discussion will help you to classify and to understand the amplifiers in your equipment.

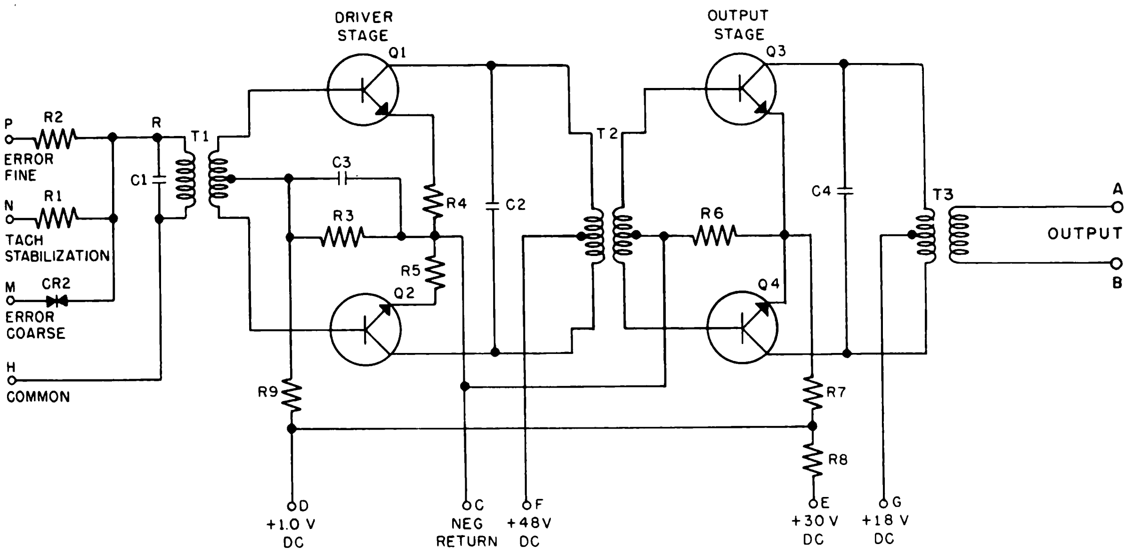
We will not discuss the theory of operation of the circuits in the amplifier, except the circuits that are unique to servos. The basic theory is covered in Basic Electronics, NavEdTra 10087-C.

Preamplifiers

In some equipment standard servoamplifiers are used. This is particularly true in instruments that have module plug-in amplifiers. Therefore, the input signal must be fairly standard within the limits of the amplifier. But servo error generators vary. For example, the error signal's amplitude may be too small for a standard amplifier, and a preamplifier is used. The preamplifier is a separate stage used to bring the signal characteristics within the requirements of the amplifier.

Transistor Power Amplifier

Figure 9-24 shows a two-stage transistor amplifier of the plug-in module type. We will assume the input error signals on pins P and M are from a dual-speed synchro control system. Zener diode CR2 is part of the synchronizing circuit and works as two diodes connected back to back. The fine signal on pin P is normally



166.21

Figure 9-24.—Transistor power amplifier.

In control. If the coarse signal becomes sufficiently large it will break down the diodes and assume control. The input on pin N is a feedback voltage from a tachometer generator. We will discuss stabilization of the servo separately later in the chapter.

The sum of the voltages on pins P, M, and N is applied to the input transformer T1. The other terminal of T1 is connected to pin H, which is a common return for the CTs and the tach. There are four supply voltages—the +1 V d.c. and the +30 V d.c. are used in a bias network, the +48 V d.c. is used as collector supply for the first stage, and the +18 V d.c. is used as the collector supply for the output stage.

Resistors R3, R6, R7, R8, and R9 form a voltage divider network to provide a fixed base-emitter bias on the transistors. The circuit for he +1 V bias is from pin D through R9 and R3 back to the negative side, pin C. The bases of Q1 and Q2 are connected to the bias circuit at he tie point between R9 and R3 through the winding of the input transformer T1. Because of the need for good voltage regulation, it is desirable not to have current flow in this circuit. Therefore, the +1V bias circuit is connected to the +30 V bias circuit at the junction of resistors R7 and R8. There is approximately +1.0 volts at this unction and most of the current drawn by the base-emitter circuit comes from the +30 V d.c. source. Consequently, the +1 V bias supply is not loaded down and voltage regulation is good.

The circuit for the +30 bias voltage is from pin E through R8, R7, and R6 back to the negative side, pin C. The base Q3 and Q4 are connected to the bias circuit through the winding of T2, the interstage transformer. The +30 bias voltage is connected to the +1 V bias voltage at the junction of R8 and R7. Thus in the biasing circuits, R9 and R3 are in parallel with R7 and R6.

The collectors of the first stage transistors, Q1 and Q2 are connected to the +48 volt supply at pin F through the primary winding of T2. The error signals from the opposite ends of T1 to the bases of Q1 and Q2 are 180 degrees out of phase with one another. The output from this stage is from the collectors, which are connected to the primary of T2 in opposition. The stage is arranged in push-pull as a driver for the second stage. The transistors are arranged in a base input—collector output circuit, with grounded emitters. The emitters are connected through R4 and R5 to the negative side. The resistors R4 and R5 furnish self-bias and help to stabilize the transistor circuits.

Transformer T2 couples the amplified error signal to the second stage. Transistors Q3 and

Q4 are base input—collector output, and are connected as a push-pull grounded-emitter circuit in an arrangement similar to the first stage. The required signal inversion is obtained from the transformer. The output of the amplifier, at pins A and B, is connected to a split-phase servomotor. The motor drives the load and the feedback tachometer generator. Response from the motor repositions the CTs to null out the error signal.

The d.c. voltages to the transistor's collectors are unfiltered and contain a ripple that is in phase with the reference voltage of the synchro system. Therefore, the error signal is either in phase or 180 degrees out of phase with the a.c. component in the collector voltages. This eliminates the need for a separate demodulator and modulator circuit.

Electron Tube Servoamplifier

Figure 9-25 shows a representative electron tube servoamplifier. We can divide the amplifier into the following functional sections: tubes V1 and V2 are voltage amplifiers, tube V3 is a phase-inverter and driver stage, and tubes V4 and V5 are the output stage connected in push-pull. The inputs to the amplifier are: the error signal on terminal 3, the plate supply voltages of +450 and +300 on terminals 4 and 5, a biasing voltage of +105 on terminal 1, and an instrument ground on terminal 2. The output is taken from terminals 6 and 7.

Before we trace a signal through the amplifier, study the biasing circuits and the plate circuits of the tubes. These are connected in a conventional manner and are covered in Basic Electronics, NavEdTra 10087-C.

We will assume the servoamplifier is used in conjunction with a dual-speed synchro control system. The input signal on terminal 3 is from a relay-operated synchronizing circuit. The signal to tube V1, a high-gain pentode voltage amplifier, is developed across the resistor R1. The output from V1 is taken from the plate and coupled to V2A through C3. The second and third stages are medium-gain voltage amplifiers consisting of the twin triode V2. The two sections of V2 are coupled by RC circuits. The output from V2B is coupled to the grid of V3A.

Both sections of V3 are connected as cathode followers to drive the output stage. The two

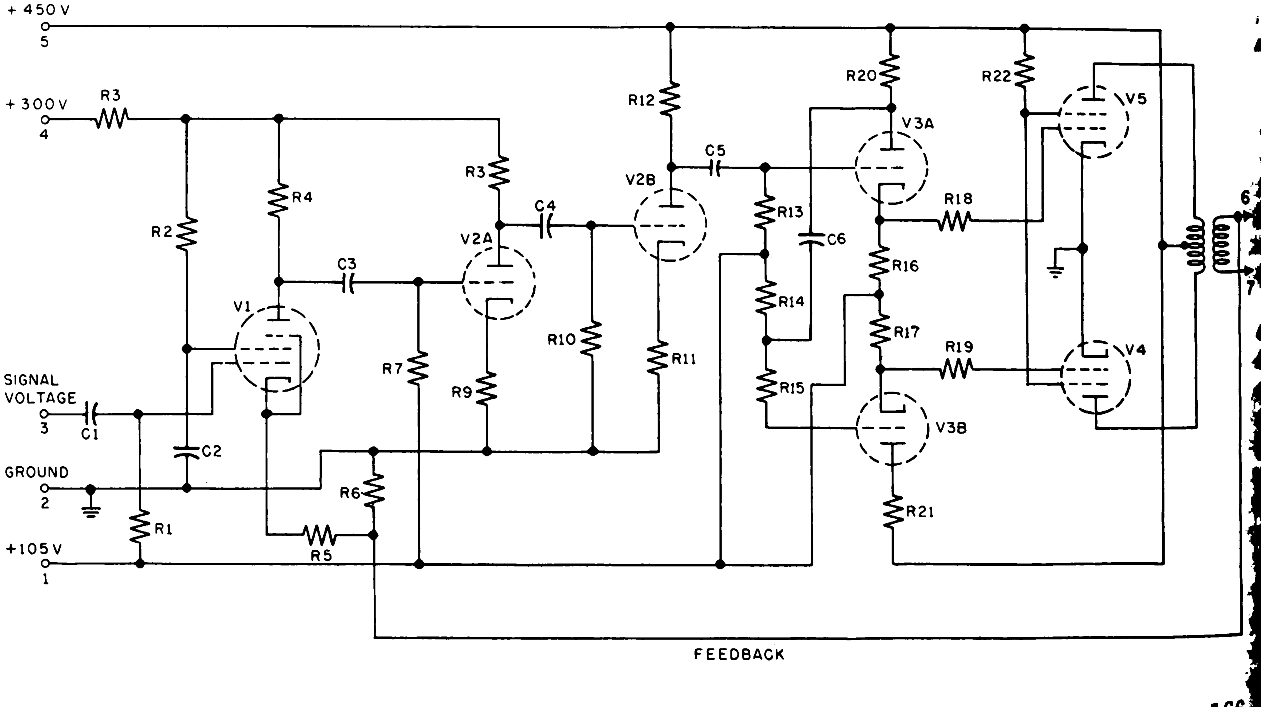


Figure 9-25.—Electron tube servoamplifier.

signals are coupled directly to V4 and V5 through R18 and R19. However, V3A has two outputs; the signal from its plate to V3B through C6 and R15 is phase inverted from its cathode output. If we assume there is no error signal on the grid of V3A, the bias on both sections of the tube will result in the cathodes being at the same potential. Therefore, the signals to the grids of V4 and V5 will be equal. Now assume that a positive signal is applied to the grid of V3A. The positive signal will cause the conduction through V3A to increase proportionally to the size of the signal. The increased current flow will cause the cathode to swing in the positive direction and the plate potential to drop. Thus the swing of the plate is a negative signal to the grid of V3B which will reduce the current flow through V3B. The cathode potential will drop in proportion to the signal on its grid. Thus the cathode of V3A has changed in a positive direction while the cathode of V3B has changed an equal amount in the negative direction. Naturally, if the signal to the grid of V3A were negative all the resulting signals would be in the opposite direction.

Tubes V4 and V5 are connected in push-pull cross the output transformer T1. The bias on e tubes in controlled by V3 — the driver stage. there is no error signal present on the grid V3A, the output tubes will conduct an equal mount in opposite directions through the primary inding of T1. The output of the amplifier will zero.

Since the signals to the grids are in opposite rections, when they are present conduction ineases in one tube and decreases in the other. e amplifier then has an output. The phase of output is determined by the polarity of the gnals to the grids, and its magnitude is prortional to the magnitude of the grid signals.

A sample of the output voltage is applied the cathode of V1 as negative feedback. The dback voltage will contain the noise comnents generated in the amplifier but their phase ll be inverted. Hence the feedback voltage ll tend to eliminate this source of noise voltage, d will also help to stabilize the amplifier. Note t there are two sources of plate supply in the plifier. The source for the last three stages the amplifier is independent of the supply for two high-gain voltage stages. This reduces amount of undesirable fluctuations in the ate supply that will be coupled between the two ctions of the amplifier. The filter circuit, and C2 forms a shunt across V1. This circuit ll decouple or shunt undesirable frequencies m the amplifier.

Magnetic Amplifiers

In electron tube amplifiers the amount of current that flows through a tube is controlled by its internal impedance. A reduction of the impedance will increase the current flow through the tube. Magnetic amplifiers use the same principle. The impedance, and consequently the current in a saturable reactor can be controlled by varying the magnetic state of its core. Magnetic circuits are covered in Basic Electricity, NavEdTra 10086-B, and will not be repeated here.

BASIC SATURABLE REACTOR. — Basically, the saturable reactor circuit has a control winding and a load winding on each of two toroidal cores (fig. 9-26). The control windings are connected so that their magnetic fields have opposite polarities. The signal resistor has a low ohmic value and the control windings have a small number of turns. The load windings present an infinite impedance when there is no signal input to the control windings, and the load current is practically zero.

A d.c. control signal impressed on the control windings will create magnetic fields in cores A and B. The magnetic fields will be stationary and opposite in polarity. The fluctuating magnetic fields created by the a.c. power supply have the same polarity in both cores and will be additive in one core and subtractive in the other core with the control magnetic fields. When the a.c. power during its first half-cycle creates additive fields in core B and subtractive fields in core A,

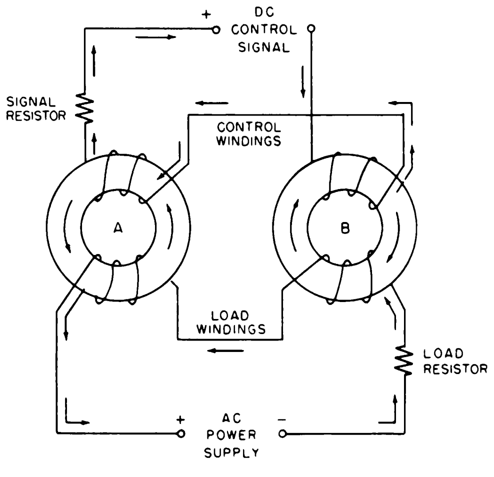


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Figure 9-26. — Basic saturable reactor.

there is a point where core B becomes saturated. The load winding on core B immediately drops towards zero impedance because, with constant flux density, there is no change in turns-linkage as the a.c. voltage varies. At the same time the impedance of the load winding of core A is considerably reduced. The subtractive magnetic fields reduce the total flux density until there is only a small rate-of-change of turns-linkages as the a.c. voltage varies. With low total flux density the windings on core A begin to function as a transformer. At this point, the control windings appear as a short circuit, and the impedance of the load windings is reduced further toward zero. Therefore, almost the entire voltage of the a.c. power supply is impressed on the load resistor.

During the second half-cycle of the a.c. supply, core A becomes saturated and core B functions as a transformer. The load resistor receives almost the entire voltage of the a.c. supply, but of the opposite phase. The amount of current through the load resistor is determined by the point in the a.c. cycle when one of the cores becomes saturated. The saturation point is determined by the d.c. control signal's amplitude. When the d.c. signal is greater, saturation is reached earlier and the period that load current flows in each cycle lengthens. Thus more current is used at the load.

The basic saturable reactor circuit does not have the stability or accuracy required for use in magnetic amplifiers in fire control equipment. To obtain better operation, the reactors have several additional windings. A regenerative winding is used with the load winding, and a bias and a negative feedback winding are used with the control windings.

REGENERATIVE WINDINGS.— The load windings are connected in series to a full-wave rectifier bridge (fig. 9-27). The regenerative windings are connected in series bucking across the bridge. When a d-c control signal is present during the first half-cycle of the a.c. supply voltage, the current through the regenerative windings will create a magnetic field of the same polarity as created by the load and control current in one core. This core (A in the figure), will drive quickly to saturation and cause the impedance of the load winding to drop to near zero. At the same time, the magnetic fields created in the other core (B in the figure) by the load and regenerative windings, tend to cancel each other leaving only the low-density flux created by the DC control signal. This core

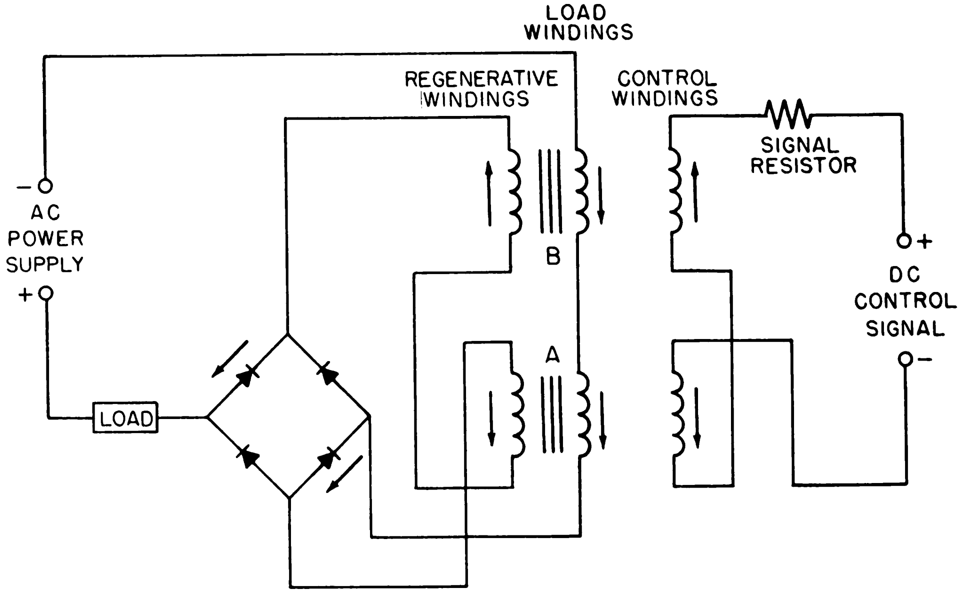

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Figure 9-27.— Regenerative windings.

will act as a transformer, in which the near zero impedance of the control winding is reflected n the load winding.

In the second half-cycle of the a.c., the current direction remains the same, except through he load windings and the load. Core B becomes saturated, and load winding B has near zero mpedance. Load winding A now acts as the transormer.

MAGNETIC AMPLIFIER IN A SERVO.—Figure 9-28 shows a practical bidirectional servo with a magnetic amplifier consisting of two saturable reactors. One-half the control winding of the a.c. ervomotor acts as the load on each reactor. The irection of the motor rotation is determined by electing the half of the control winding through which current will flow. The saturable reactors A and B are similar to the one in figure 9-27 with the exception that we have added the bias and negative feedback windings.

BIAS AND FEEDBACK WINDINGS.—The efficiency and accuracy of a magnetic amplifier are lowered by the magnetic hysteresis of the core material. Hysteresis is the lag of the magnetic flux behind the current that causes it. The two bias windings in each reactor are wound in opposite directions. Therefore, the magnetic fields created by the d.c. bias current have opposite polarities. To counteract the lag, the bias magnetic fields tend to cause the magnetic fields in the core to reverse polarities with the a.c. voltage supply. The amplitude and direction of the bias current is set so that when the control signal has the same polarity it will prevent reactor B in the figure from saturating. When the bias and control signals have opposite

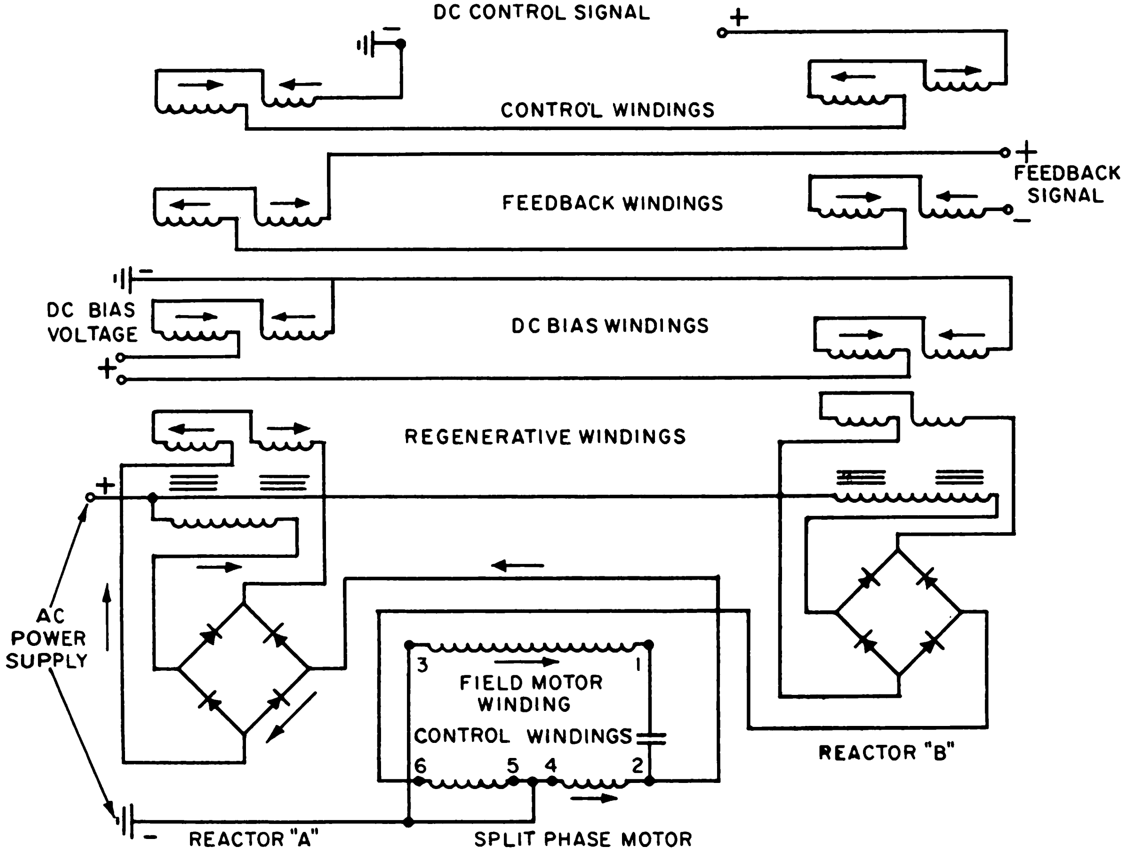

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Figure 9-28.—Magnetic amplifier in a servo.

polarities, the bias will stop reactor A from conducting.

The d.c. control signal (fig. 9-28) is positive, and saturable reactor A will conduct. The direction of current flow through the motor's control winding 2-4, which is the load on the reactor, corresponds to the current in the motor's field winding 1-3. During the negative half-cycle of the a.c. supply the current in both the control and field windings of the motor will reverse. Therefore, the motor will continue to drive in the same direction. Basically, the operation of the saturable reactor is identical to the one in figure 9-27. As long as the input control signal polarity remains the same, reactor A will continue to conduct. Reactor B is prevented from conducting by its bias voltage.

If the polarity of the input signal becomes negative, reactor B will conduct and pass current through motor control winding 5-6. Current direction through the motor control winding is opposite to that in the motor field winding. The motor will now rotate in the opposite direction. Reactor A is prevented from saturating by its bias current. Thus we have a bidirectional servosystem.

The negative feedback voltage is taken from the output motion of the servo. Its polarity is opposite to that of the control signal voltage input to the amplifier. The feedback voltage serves the same purpose as in an electron tube amplifer. It will dampen the servo, reduce the noise in the output generated in the amplifier, and help to stabilize the system.

Isolation Amplifiers

Isolation amplifiers are used with computing components, such as resolvers and potentiometers, to increase their accuracy. Some other names for an isolation amplifier are: buffer, booster, and operational amplifier. The amplifier has a high input impedance and thus draws practically no current from the signal source. It separates the signal source from its normal load, and inaccuracies that would result from loading the signal source are thereby greatly reduced. As you know, a resolver's output signal is a scale voltage representing a quantity in the fire control problem. We cannot afford errors in the scale voltage.

The isolation amplifier is a power amplifier with a voltage gain slightly greater than unity. Its output voltage has either no phase shift or a designed and controlled phase shift. The voltage gain beyond unity compensates for the losses incurred in the particular component with which it is used.

COMPUTING AMPLIFIERS.—When you studied amplifiers in Chapter 6, you learned that computing amplifiers are sometimes used to isolate a signal source from a load. Therefore, you are familiar with the operating principles of isolation amplifiers. Generally speaking, they have a high, variable gain factor. When used as isolation amplifiers, they use a high percentage of negative feedback to buck against the input signal. Let's expand our knowledge of these principles by analyzing two other isolation amplifier circuits. First, a basic isolation amplifier circuit. Second, an electron tube isolation amplifier.

BASIC ISOLATION AMPLIFIER CIRCUIT.—The isolation amplifier eliminates direct connections between the signal generator and the resolver Re1 and its load resolver Re2 (fig. 9-29) The amplifier is in series with the load. Firs we will consider the voltage regulating circuit- trace out the heavy lined loop. The input to th amplifier is the instantaneous potential differenc between R1 of Re1 and ground. The amplifier outputs are taken from the voltage dividers R and R4. The voltage across the resistors i applied to Re2, the load. Resistor R4 determine the amount of negative feedback to Re1 and the amplifier. The value of R4 is selected so tha the feedback is slightly less than unity. The amplification factor is slightly greater than unity in order to make up for resolver trans formation losses.

The portion of the amplifier's output acros R4 is connected back to the signal source, Re We can look at the negative feedback voltage a balancing voltage supply. When Re1 produc a signal to the amplifier, the feedback voltag whose amplitude is proportional to the signa voltage is sent back to balance it. Thus the sig from Re1 "sees" the impedance of the amplifi input circuit plus the impedance of a relat but separate source of supply in the feedba circuit. Therefore, practically no current drawn from Re1 and the signal voltage is co stant and regulated The load current for Re2 drawn from the amplifier and not from the sign generator Re1.

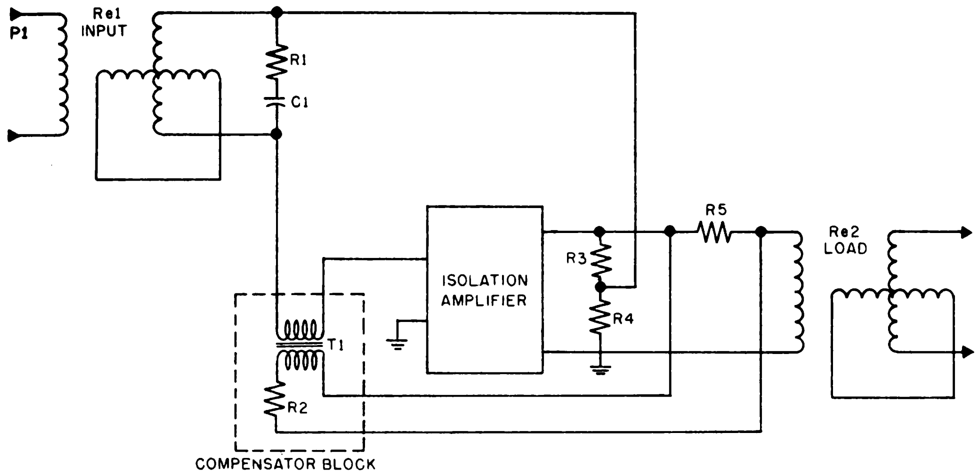

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Figure 9-29.—Isolation amplifier circuit.

PHASE COMPENSATOR CIRCUIT.—We can ontrol the phase shift in the amplifier by circuit lesign. But what of the phase shift caused by the nductive load in Re2? The inductive reactance of he coil will cause the load current to lag its oltage by almost 90 degrees (fig. 9-29). The esistance of R5 is small compared to the in- uctive reactance of the coil. The voltage across 5 is developed by the load current and therefore s in phase with the current and lags the load oltage by almost 90 degrees. The R5 voltage is measure of the phase shift caused by the load eactance and is used as a feedback voltage.

The feedback voltage is combined with the put to the amplifier at T1. This feedback, since lags approximately 90 degrees, is often re- rred to as quadrature feedback; it shifts the hase of the input signal just enough to cancel le phase shift in the Re2 coil. Thus, the com- nsator network maintains the Re2 input at the me phase as the Re1 output.

ELECTRON TUBE ISOLATION AMPLIFIER.— gure 9-30 shows a representative electron be isolation amplifier. There are two voltage plification stages, using triodes V1 and V3, d a push-pull output stage using triodes V5 and 7. Phase inversion for the push-pull stage is tained by using a portion of the output of V5 r the input grid signal to V7. In this way the id inputs to V5 and V7 are 180 degrees out of ase with each other.

Several RC networks are used to attenuate high-frequency harmonics. They are the R47-C7 network across the output of V1, the R27-C19 network in parallel with the primary of output transformer T3, and the R33-C21 combination across the secondary of T3. The R23-C15 network which connects the output of V5 to the cathode of V3 provides high-frequency attentuation through degenerative feedback. The R11-C9 network connecting the output of V1 to the grid of V3 shifts the phase of any existing low-frequency harmonics to prevent oscillations.

Fixed bias for the first two stages is provided by the voltage dividers in the cathode circuits, R5-R45 for V1, and R15-R17 for V3. The bias of V5 and V7 is provided by the common cathode resistor R29. The bias is determined by the amount of current flow through both tubes.

COMPARISON OF A. C. AND D. C. SERVOS

Generally speaking a.c. and d.c. servos are similar. They both meet the basic requirements of a fire control servo and have essentially the same components. The type of servo used is determined by the requirements of the load. Heavy loads with a wide speed range, such as, directors and radar antennas, are controlled primarily by d.c. servos. Light loads with a fairly constant speed requirement are normally

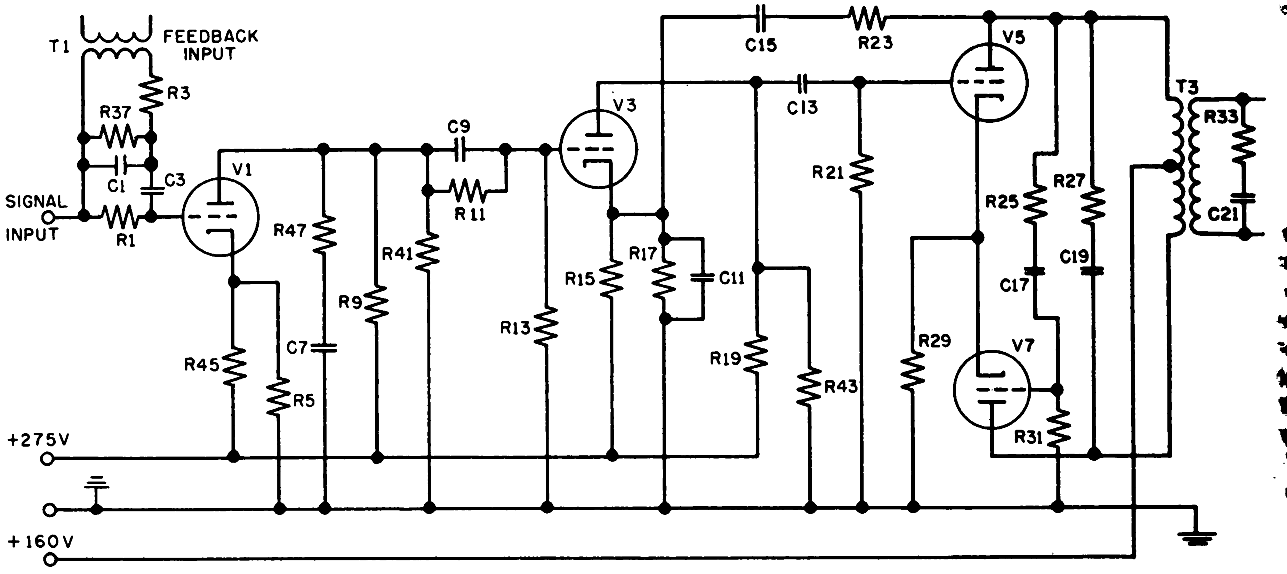


Figure 9-30.—Representative electron tube isolation amplifier.

controlled by a.c. servos. The characteristics of a.c. and d.c. servomechanisms will tell us why this is so.

AC SERVOMOTORS

Large a.c. motors are too inefficient for servo use. To obtain the desired torque-speed output curve the motor becomes too large, draws excessive power, and is difficult to cool. Hence a.c. servos in fire control equipment are used primarily to control light loads which require low power. Most of the a.c. servomotors are of the two-phase or split-phase induction type. Fundamentally, these motors are constant-speed devices, although their speed can be varied within limits by varying the amplitude of the voltage to one of the motor's stator windings.

The voltages to the stator windings of a two-phase motor should be exactly 90 electrical degrees apart. The 90° phase relationship can be established by shifting the phase of the voltage to either of the stator windings. Any phase shift that changes the 90° relationship will reduce the motor's efficiency. The direction of rotation of the motor can be changed by reversing the phase relationship between the stator windings.

DC SERVOMOTORS

The control characteristics of d.c. servomotors are superior to those of a.c. servomotors The d.c. servomotor can control heavy loads variable speeds. Most of the d.c. servomotor found in fire control equipment are either the permanent magnet type which are used for light loads, or the shunt field type which are used fo heavy loads. The operational characteristics these motors are covered in Basic Electricity NavEdTra 10086-B. When they are used servos, the strength of the motor's field which supplied by the magnet or shunt field is held co stant. The direction and the speed of the motor rotation is determined by the armature current, which is supplied by the servoamplifier. An increase in armature current will increase th motor's speed. A reversal of the motor's arm ture current will change the motor's directi of rotation.

A disadvantage of d.c. servoamplifiers their tendency to drift. Drift is the low frequen variation of the output voltage with no change the input. Drift is usually caused by changes i power supply voltages or by the change of component values due to temperature variation aging effects, and humidity. Drift in d.c. serv amplifiers can be overcome by circuit desig Frequently, however, an a.c. amplifier is use

d the output is demodulated. As a result, in
me servos you may find modulation and de-
odulation stages which, on the surface at least,
em purposeless.

OPERATIONAL ACCURACY

A servo should drive rapidly toward the
ed correspondence point of a steady state of
atic signal. It should synchronize with a mini-
um of motion in the shortest time. Once
nchronized, the servo should hold its position
gidly at the correspondence point. Where the
put order signal is continuously changing posi-
on, the servo must drive to the correspondence
int in the same manner as with a fixed signal.
ce in correspondence, the servo must drive
the same rate as the input order signal.

In a position control servo, the rate of
ovement is established by the rate of displace-
ent. Hence there is a definite lag between the
der signal position and the output position.

The accuracy of a servo is determined by its
ility to measure and produce an error signal
d to amplify the error signal to a level which
ll move the load to eliminate the error. Hence
overall accuracy of a servo is determined by
accuracy of its components and their input
a.

The error detector receives and compares
ordered position and the actual position of
servo's output. Any error in the input data
l naturally reduce the accuracy of the error
ector's output. The accuracy of the error de-
tor is determined by the amount of difference
ween its inputs that is necessary to produce
sable error signal.

The gain of the servoamplifier determines
large the error signal must be before
plifier output is sufficient to drive the error
ucer. The higher the gain, the more sensi-
the amplifier and the more accurate the
vo. The efficiency of the error reducer
ermines how large the control current must
before it will drive.

The accuracy of the data, error detector,
voamplifier, and error reducer determines
static error or dead space of the servo. The
ic error is the angular displacement between
input and output of the servo under static
conditions, (synchronized to a fixed order signal). The static error under load is the angular lag between the input and output of the servo when the input signal is moving at a constant velocity. The static errors are sometimes called steady state errors.

We have taken a negative approach to accuracy to show that servos have inherent sources of errors. Because of the errors, the term "null voltage" is used rather than "zero voltage," when the servo is synchronized. But do not get the false impression of large errors; the accumulative error in fire control servos is small. Multiple-speed data transmission systems are used to increase the accuracy of servos. Multiple-speed synchro systems are covered in chapter 11 of this text. Servos have high gain amplifiers to increase accuracy.

GAIN, PHASE, AND BALANCE ADJUSTMENTS

In many servosystems the gain of the amplifier can be varied by an adjustment. The gain adjustment governs the amplitude or amount of the signal voltage applied to the amplifier or one of its stages. Normally, the highest gain possible, with the servosystem possessing a satisfactory degree of stability, is the most desirable.

In a.c. servosystems another adjustment which can control the sensitivity of the system is the phase adjustment. The phase adjustment is used to shift the phase relationship between the signal voltage and a reference voltage. In an amplifier with phase shift control the grid signal is shifted in phase with reference to the plate voltage of a tube. The tube's firing point is delayed or advanced depending upon the phase shift of the grid signal. The phase shift can vary the firing time of the tube over the plate's entire positive alternation.

A phase control is included in some servosystems using a.c. motors. The two windings of the a.c. servomotor should be energized by a-c voltages that are 90° apart. This phase adjustment is included in the system to compensate for any phase shift in the amplifier circuit. The adjustment may be located in the control amplifier, or, in the case of a split-phase motor, it may be in the uncontrolled winding.

Servosystems using push-pull amplifiers must be balanced so that when there is no signal input to the amplifier, its output will be zero, and the servomotor will stand still with no creep. The push-pull amplifier must ensure equal torque in both directions of the servomotor.

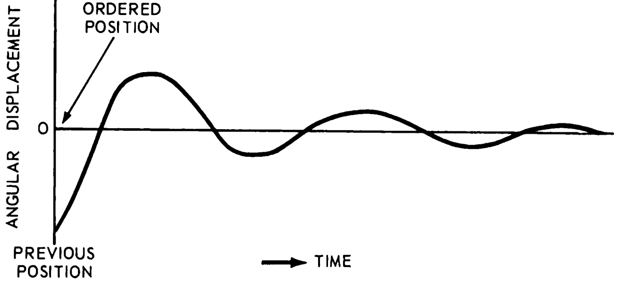
Gain, phase, and balance adjustments are often present in one amplifier. These adjustments tend to interact, so that when one of them is changed it may affect the others. Therefore, after making any one adjustment it is a good practice to check the other adjustments.

RESPONSE TIME

Fire control requires a servosystem to operate smoothly, rapidly, and with as few errors as possible. To obtain these operational characteristics, one quality is counterbalanced against the other. To increase the rapidity of response of the system to a signal, the gain is increased. This also tends to reduce error in the system. But a high gain or "tight" servo has a tendency to overshoot and oscillate, or, in other words, to be unstable. Response or synchronization time is the time the servo requires to settle down in synchronization to an order signal.

"HUNTING"

A servo will drive its load to the correspondence position. The servo's error signal and output torque are zero at correspondence, but due to the load's inertia it will continue to move. As the correspondence point is passed, the error signal tends to reverse the direction of movement. But a short time is needed to stop the load; and, during this time, the load will continue to move away from correspondence. When it does stop, the error signal will drive the load back towards correspondence. At correspondence the load has again acquired sufficient inertia to drive on past. The result is a series of overtravels of the correspondence point (fig. 9-31).



12.290

Figure 9-31.—Overtravels of the correspondence point.

This condition is called "hunting", and is a characteristic which must be corrected in all servos. Obviously, hunting reduces the smoothness of the servo's followup action and increases its synchronization time. To overcome hunting, the servo must anticipate the load's inertia and its position with respect to the correspondence point.

When a servo is hunting, its oscillations about the correspondence are of a low frequency A servo with a high gain amplifer has a tendency to oscillate at a high frequency with a low amplitude. The high frequency oscillations are started by some type of disturbance or variation such as random noise in the electrical section of the servo or lost motion in the mechanical section. Once the oscillations are started, the high gain of the amplifier tends to assist them while the inertia of the load continues to reintroduce the error caused by the oscillation.

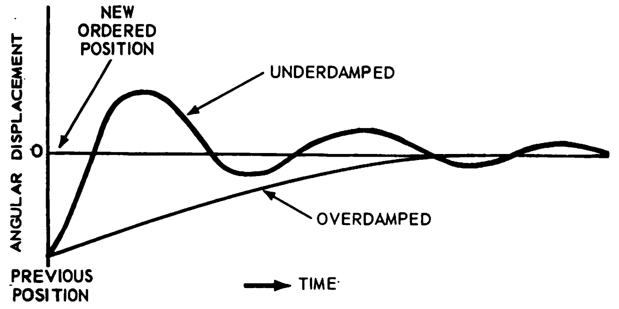
STABILIZATION

To obtain smoothness of operation, the system's gain is damped. Damping can be obtained by either introducing a voltage in opposition t the signal voltage or placing a physical restrain on the servo output. The function of damping i to reduce the amplitude and duration of th oscillations that may exist in the system. Ever system has one or more natural oscillatin frequencies which depend on the weight of th load, designed speed, and other characteristics

DEGREE OF DAMPING

The degree of damping is determined by th required operating characteristics of the servo system. If the system is OVERDAMPED, it wi not oscillate about the correspondence poi However, due to the large amount of restra placed on the servo, it will have a comparativ large dead-space or steady-state error. T overdamped servo will also take an excessiv long time to synchronize (fig. 9-32).

On the other hand, the UNDERDAMP servosystem will have instant response to error signal. But it will have erratic operati due to the low amount of restraining force pla on the servo, and will oscillate about the po of synchronism. Somewhere between these t extremes, we can obtain adequate accuracy a



12.291
Figure 9-32.—Degree of damping.

smoothness plus a moderately short synchronizing time.

TYPES OF DAMPING

Viscous Damping

The simplest form of damping is viscous damping. This is the application of friction to the output shaft or load that is proportional to the output velocity. The amount of friction applied to the system is critical, and will materially affect the results of the system. The application of friction absorbs power from the motor, and this power is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper, but with somewhat less power loss, is used in actual practice. The first damper of this type to be discussed utilizes a friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel has the property of inertia.

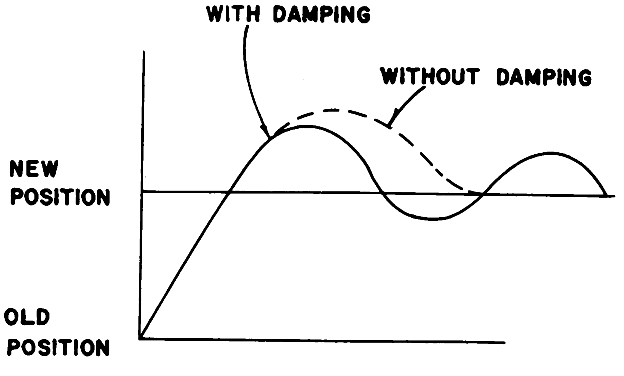
FRICTION CLUTCH.—As the servomotor rotates, the clutch will couple a definite amount of this motion to the flywheel. The flywheel will gradually overcome its inertia and gain speed until it approaches the velocity of the motor. The flywheel in turning absorbs energy (power) from the servomotor. The amount of energy stored in the flywheel is determined by its velocity. Because of inertia, the flywheel will resist any attempt to change its velocity.

As the point of correspondence is neared and the error signal is reduced, the motor starts to slow down. The flywheel immediately releases some of its energy into the output shaft in an attempt to continue at the same speed. Thus the flywheel will cause a large first overtravel. The servosystem, to correct for this overtravel, reverses the direction of the motor. Once again the flywheel resists the motor movement and absorbs energy from the system. This drastically reduces the second overtravel and all subsequent overtravels of the motor. This effect dampens the oscillations about the point of correspondence and reduces the servosystem's synchronizing time.

The motor rotation is transmitted to the flywheel through the friction clutch. The inertia of the flywheel is an additional load on the motor. The friction clutch will slip with any rapid change of direction or speed. This slipping effectively disconnects the flywheel instantaneously, and thus governs the amount of power the flywheel will draw from the motor.

MAGNETIC CLUTCH.—Another type of viscous damper is the MAGNETIC or EDDY CURRENT damper. The magnetic damper is functionally similar to the friction clutch damper. The principal difference between the two is in the method of coupling the flywheel (inertia weight) to the servomotor output shaft. In the magnetic damper, the shaft and flywheel are coupled by a magnetic field, rather than a frictional contact. The coupling is made by the interaction of a magnetic field generated by a permanent magnet which rotates with the rotor of the servomotor and the induced eddy current in the flywheel.

The effect of viscous damping is shown in figure 9-33. The solid line shows the action of the load without damping. The time required to



55.38.0
Figure 9-33.—Effect of friction damper.

reach a steady-state condition should be noted. This time is greatly reduced with damping, although the initial overshoot is increased. Viscous dampers effectively reduce transient oscillations, but they also produce an undesirable steady-state error (velocity lag or position error). Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

Error-Rate Damping

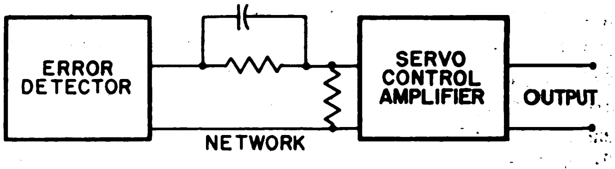
Since no physical device can respond instantaneously to a sudden force, there is a time lag between the signal input of a servosystem and its output response. To reduce this time lag, amplification is increased. We know that this also accentuates the tendency of the system toward instability. Viscous dampers act as part of the servo load, so they are not the answers to reducing the response lag. The answer lies in increased amplification with error-rate damping.

Error-rate damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is combined with the error signal in the proper ratio to obtain optimum servo operation with negligible overshooting and oscillations.

The advantages of error-rate damping are:

1. Maximum damping occurs when a maximum rate of change of error signal is present. This normally would occur when the servo load reverses direction. Obviously, this is when maximum damping action is required.
2. Since a CHANGE in the signal causes damping, there is a minimum amount of damping when no signal, or a signal of constant strength, is present. This means small steady-state errors.

Error-rate voltages are generated by either electromechanical devices or electrical networks in fire control equipment. An electromechanical device widely used to generate an error-rate voltage is the tachometer generator. The tach is mechanically coupled to, and rotates with, the servo's output shaft. Its output voltage is proportional to the output velocity of the servo. Since the voltage output is proportional to load velocity it is also proportional to the inertia of the load due to its velocity. Hence the output voltage can be fed back to the amplifier to indicate the load's velocity and therefore its inertia.



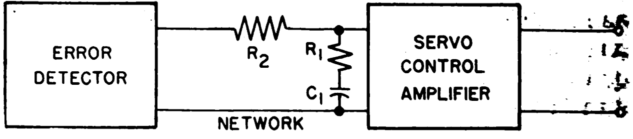
55.41

Figure 9-34.—Error rate stabilization network.

ELECTRICAL ERROR-RATE VOLTAGE NETWORKS.—Electrical networks used for error-rate damping consist of a combination of resistors and capacitors forming an RC differentiating network. From your study of basic electricity, you know that a differentiating circuit produces an output voltage that is proportional to the rate of change of the input voltage. In an RC circuit, if the voltage across the resistor is used as the output, it is referred to as a DIFFERENTIATOR (fig. 9-34), and if the voltage across the capacitor is the output, it is referred to as an INTEGRATOR (fig. 9-35).

Servos used in fire control equipment are required to follow an input signal which is sometimes changing at a constant rate and sometimes at a variable rate. A director's train power drive is an example of a servo whose input signal may be fixed, changing at a constant rate, or at a variable rate. When the director is tracking a target on a steady course and speed, the train rate may be constant. However, if the target changes course or speed the director train drive may require a sudden acceleration. It can be seen that this servo must adapt itself to a variety of signal types, and respond to them with substantially zero error.

Let's use the integrator circuit shown in figure 9-35 or, as it is sometimes called, an integral control—to explain error-rate damping. The integral control circuit is shown in its simplest form. It is made up of a combination of two resistors and a capacitor. Notice that



55.42

Figure 9-35.—Integrator used as an integral stabilization network.

the network is in series with the error detector and the amplifier. The circuit is designed for d-c signals; if the error detector puts out an a-c signal, it must be demodulated before it enters the network. The signal is dropped across R_2 and the R_1, C_1 leg of the network. The R_1, C_1 leg is in parallel with the amplifier's input circuit. Therefore, only that portion of the signal developed across the R_1, C_1 leg is fed into the amplifier. R_2 is in series with the leg and is larger than R_1. Briefly, here is how the circuit works.

Assume that the error signal is steady or changing slowly. Initially, all of the constant error voltage is divided between R_1 and R_2. But the longer the error voltage is applied, the more C_1 charges up. The increasing voltage drop across C_1 adds to the drop across R_1. Since these two components are in parallel with the amplifier, their combined voltages will appear at the input terminals of the amplifer. In effect, the servo will overcorrect the error signal and the output shaft will catch up with the input signal. As the drive increases its velocity it will reduce the error signal. The capacitor C_1 will start to discharge and oppose the reduction. The damping action of the capacitor's charging and discharging voltages, which oppose the changes in the error signal, we assist the servo to settle down quickly at the new velocity.

The discussion of an integral control is by no means complete. There are many types of RC circuits and many different applications of heir use for error-rate damping in servos. The discussion does cover the fundamental operation of an electrical RC network which can provide error-rate damping.

FREQUENCY RESPONSE

At first, we considered the order as being uddenly put at a fixed value. Later, we studied he case where the order slowly increased in value, where it was constantly moving. Actually, he order to a servo may accelerate, start, top, or oscillate about a fixed point. We will ow consider actions of a servo while the order scillates. When the order is constant, oscillations of the load are undesirable. When the rder oscillates, the load must oscillate in a imilar manner.

Meaning Of Frequency Response

The frequency response of a servo depends pon the range of frequencies over which the order may oscillate, and still produce similar oscillations in the load.

Assume that an oscillating order is put into a servo. The load may behave in several ways. Ideally, it would oscillate at the same frequency, amplitude, and phase as the order. Actually, the amplitude and phase of the load are different from those of the order, figure 9-36. The frequency is usually the same as that of the order.

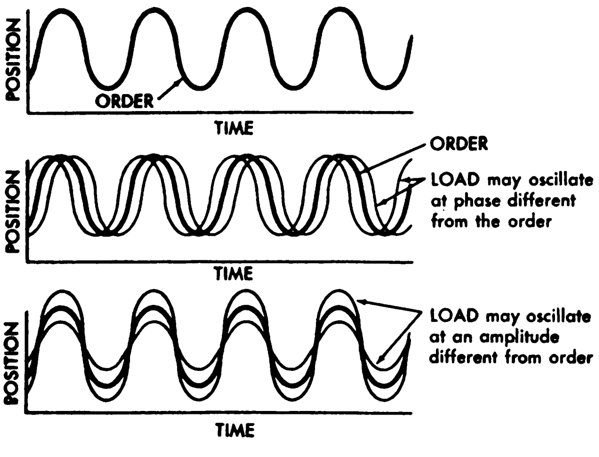
A servo may follow the order in amplitude, and differ in phase, it may follow the order in phase and differ in amplitude, or it may differ in both phase and amplitude.

Effect Of Gain And Damping On Frequency Response

The higher the frequency of the order, the more difficult it is for a servo to accurately follow it. Damping and gain affect frequency response similarly to the way they affect lag. High gain, and low damping, will improve the frequency response.

Frequency response is a good way of judging servo performance, because good frequency response involves a balance of damping and gain, so that maximum stability and least lag are attained. If a servo responds accurately to a wide range of frequencies, it has a correct balance between damping and gain.

Assume that a high frequency order is being put into the servo. If the servo has high gain, and low damping, the rapidly increasing

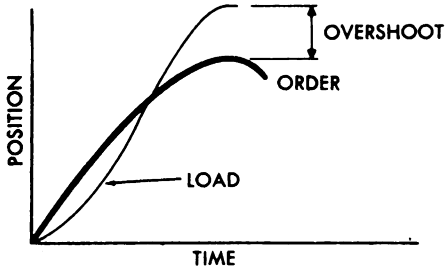

POSITION
ORDER
TIME
ORDER
LOAD may oscillate at phase different from the order
POSITION
TIME
LOAD may oscillate at an amplitude different from order
POSITION
TIME

167.782

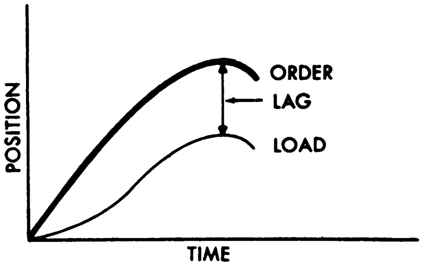
Figure 9-36.—Frequency response.

error at the beginning of the ordered motion will cause the load to leap to a response, and catch up to the order. However, when the order reverses direction, low damping and high gain will cause the load to overshoot, as shown in figure 9-37.

If the servo has low gain, and high damping, the load will move slowly while the order is changing rapidly, causing a large lag. However, when the order changes direction, the low gain will cause little overshoot, as shown in figure 9-38.



167.783
Figure 9-37.—High gain-low damping.



167.784
Figure 9-38.—Low gain-high damping.

CHAPTER 10

PRINCIPLES OF GYROS

INTRODUCTION

The purpose of this chapter is to provide you with basic information on gyroscopic principles and the applications of gyroscopes in fire control equipment. Emphasis has been placed on basic fundamentals and functions of gyroscopes, rather than on details of construction, repair, and maintenance.

The gyroscope, commonly called a gyro, has existed ever since the first electron was sent spinning on its axis. Yes, electrons spin and show all the characteristics of a gyroscope. And so does the earth, which spins about its polar axis at high speed. It is interesting to note that any point on the equator travels at a speed of over 1000 miles per hour, which is about three times as fast as the gyros you are going to work with.

After completing this chapter, you will have an understanding of gyroscopes and how they can be used. For instance, you'll know how gyro is utilized to establish the local horizontal plane which is a reference plane for the fire control problem that you studied in chapter 3. You will acquire knowledge of gyro applications in automatic radar tracking systems, and learn how they are used to determine rates of movement. Finally, you will see how gyro-developed signals are used to control the flight attitude of a missile in flight.

WHAT IS A GYROSCOPE?

Any rapidly spinning object — a top, wheel, an airplane propeller, or a spinning projectile — is fundamentally a gyroscope. Strictly speaking, however, a gyroscope may be defined as a mechanical device containing a spinning mass which is universally mounted, that is, mounted so it can assume any position in space. Figure 10-1 shows a model of a gyro. As you can see, a heavy wheel is mounted so that its spin axis is free to turn in any direction. The wheel can spin about axis x, it can turn about axis y, and finally turn about axis z. With this mechanical arrangement the spinning wheel can assume any position in space. Thus our model gyro meets the requirements of the definition.

HOW IT GOT ITS NAME

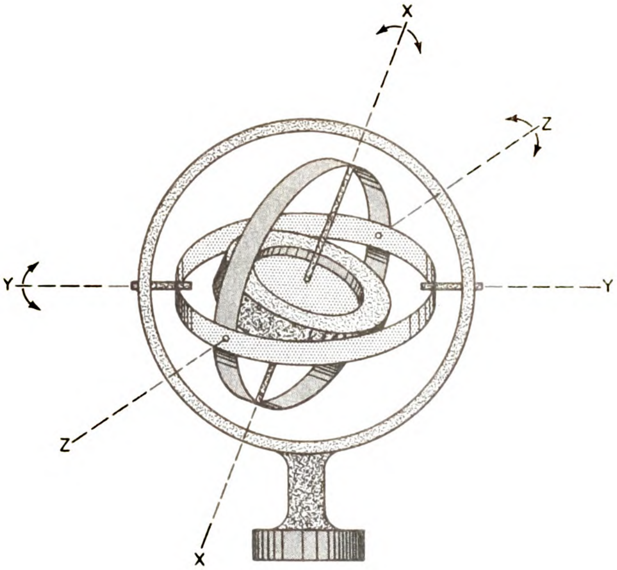
The word gyroscope was first coined by the French scientist, Leon Foucault, in 1852. Foucault made his first gyroscope for the purpose of demonstrating the rotation of the earth. The word gyroscope is derived from the Greek words "gyro," meaning revolution and "skopein," meaning to view. Combined, the term means "to view the revolution of the world."

Although Foucault lived over one hundred years ago, there was at that time no completely satisfying demonstration of the theory that the earth was a rotating body. There were people who still clung to the idea that the earth stood still and the sun, moon, and stars moved around it. Foucault wanted to demonstrate the earth's rotation by something on the earth itself. He mounted a wheel in a frame on very delicate bearings so that it could maintain its spinning axis in a fixed direction. He was able to show that the earth did revolve in relation to the fixed direction of his experimental gyroscope. Because his new instrument made the rotation of the earth visible, he combined the two Greek terms mentioned above and called the instrument a gyroscope.

BASIC PROPERTIES OF GYROSCOPES

Gyroscopes have two properties which make them useful in fire control:

1. The axis of rotation (spin axis) of the gyro wheel tends to remain in a fixed direction in space if no force is applied to it.
2. The axis of rotation has a tendency to turn at a right angle to the direction of an applied force.



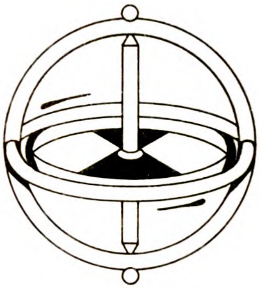
12.137
Figure 10-1.—Gyro model, universally mounted.

The idea of maintaining a fixed direction in space is easy to show. When any object is spinning rapidly, it tends to keep its axis pointed always in the same direction. A toy top is a good example. As long as it's spinning fast, it stays balanced on its point. Because of its gyro action, it resists the tendency of gravity to change the direction of its axis. You can think of many more examples. A bicycle is easier to balance at high speed than when it's barely moving. At high speed, the bicycle wheels act as gyros, and tend to keep their axes parallel to the ground.

(Note that it's easy to MOVE the axis as long as you keep it pointing in the SAME DIRECTION. The gyro resists only those forces that tend to change the direction of its axis. In a bicycle, since the axis of rotation is horizontal, the wheels will resist any force that tends to tilt the axis, or turn it.)

Any wheel that's spinning fast will show gyro action. The heavier the wheel, and the faster it is spinning, the stronger the gyro action. You can make this action stronger by concentrating the weight of the wheel near its rim.

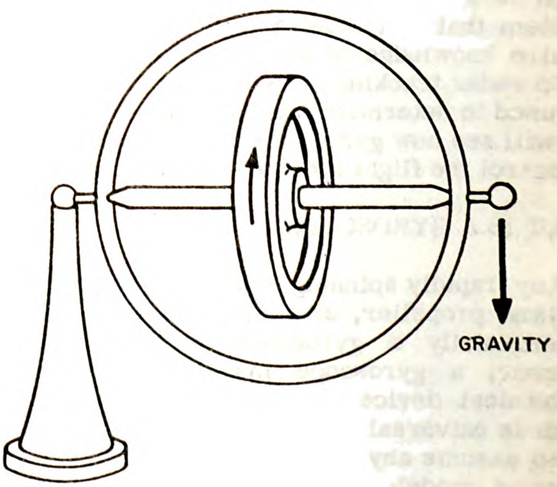
If you can get hold of a gyroscope top, like the one in figure 10-2, you can do some instructive experiments with it. Hold your gyro top with its axis vertical, as in figure 10-2, and start it spinning. As long as it is spinning fast, it will stay balanced. You can balance it on a string or on the end of your finger; the axis will stay vertical as long as the top is spinning fast.



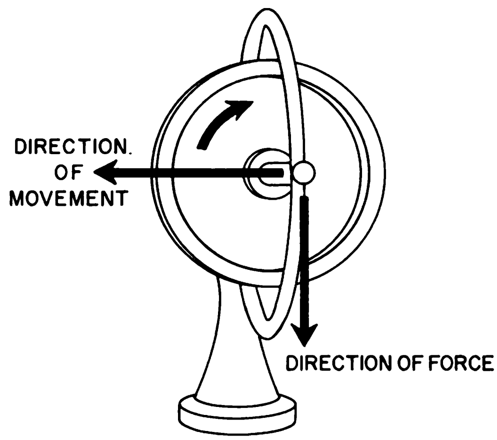
4.98
Figure 10-2.—A gyroscope top.

Now stop the gyro top and turn its axis horizontal. Start it spinning again and balance one end on a pivot, as in figure 10-3. What happens now? If the top is spinning fast, it won't fall. Its axis will stay horizontal, resisting the tendency of gravity to change its direction. But while the gyro will resist the force that gravity applies to it, it will still RESPOND to that force. And it responds by moving its axis at a RIGHT ANGLE to the APPLIED force.

Figure 10-4 is another view of the same gyroscope. Its far end is still balanced on the pivot.



4.99
Figure 10-3.—Gyro top with axis horizontal.



4.100
Figure 10-4.—Gyro precession.

Gravity is pulling down on the near end of the frame. If the gyro rotor is turning in the direction shown by the arrow, then the near end of the frame will turn to the left. (If the rotor is turning in the opposite direction, the frame will turn to the right.) The axis will stay horizontal, but the gyroscope will respond to the force of gravity by rotating around the pivot.

Gravity is a force that acts along parallel lines upon each particle of matter that makes up the gyro. Each force acts independently of all other forces, but force is a vector quantity having both a direction and a magnitude. Therefore, we can plot a resultant of the forces of gravity acting on the gyro. The magnitude of this single force is exactly equivalent to the separate parallel forces. Its point of application is called the center of gravity. In order to have a balanced gyro, the center of gravity must be located at the intersection of the three axes of the gyro. This must be true when the gyro is not spinning, for a static balance; and when it is spinning, for a dynamic balance.

We can summarize gyro action like this: A spinning gyro tends to keep its axis pointing in the same direction. This is called rigidity. If you apply a force that tends to change the direction of the spin axis, the axis will move at a right angle to the direction of the force. If the axis is horizontal, and you try to TILT it, the axis will turn. If the axis is horizontal, and you try to turn it, the axis will tilt. This second characteristic of a gyro is called precession.

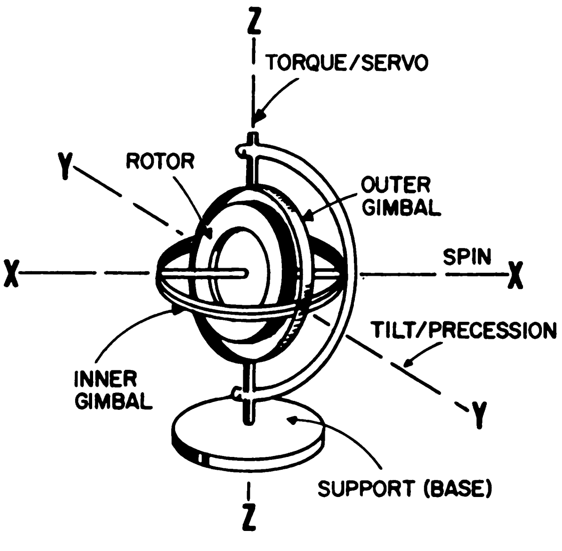
BASIC GYRO ELEMENTS

The gyro shown in figure 10-5 is a basic universally mounted gyro. The components are: rotor, inner gimbal, outer gimbal, and base or support. The three major axes of any gyro are the spin, torque or servo, and precession. The spin axis is, of course, he axis on which the rotor spins. The torque or servo axis is the axis about which the disturbing force is applied. The precession or tilt axis is the axis the gyro turns about as a result of the force applied to the torque axis.

The term gimbal may be defined as a device for permitting a body to incline freely in any direction and retain that position when the support is tipped or repositioned. Note that in figure 10-5 the support may be moved about all three axes without the rotor position being disturbed. Rigidity in space is clearly shown in fundamental form by this demonstration.

WHERE GYROS ARE USED

Gyros, because of their unique properties, are used in all fire control systems. A gyro is capable of measuring the angular displacement of its support mounting from its spin axis or reference plane. Because the spin axis of the gyro is fixed in space, the gyro can provide



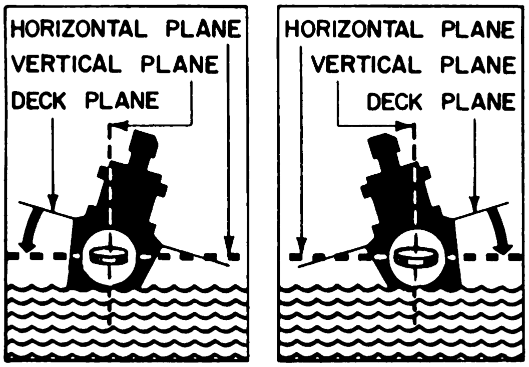
12.138
Figure 10-5.—Basic universally mounted gyro.

stabilized reference planes from which the various angles, lines, and motions in the fire control problem can be measured. In figure 10-6 the gyro represents the stabilizing unit of a fire control system. The gyro, due to its rigidity, is unaffected by the ship's roll and pitch. In a manner of speaking, the ship is rolling about the gyro. The gyro measures the angular displacement of the deck plane out of the horizontal plane. Corrective signals that are a measure of the displacement are generated to obtain a stabilized problem.

In the days of wooden ships a simple pendulum was used to measure the ship's motion with respect to the earth. The pendulum was suspended so that it was free to align itself with the earth's gravitational pull. By watching the swing of the pendulum the gun battery could be fired at any desired point in the ship's roll. Today, however, the gyro is used for stabilization. Later in this chapter we will discuss stabilizing units in more detail.

A gyro can be used to determine the angular velocity of its support mounting about a reference plane. Since a gyro will precess when acted on by an external force, we can use this property of a gyro to obtain angular velocity. For example, a special type of gyro can be mounted in a director so that the angular motion of the director is a force acting on the gyro. The gyro will precess an amount directly proportional to the angular rate of the director's motion. We will cover this type of gyro, the rate gyro, later in this chapter.

Gyros have many applications in a variety of fields. We've already mentioned their use in guided missiles. Their applications are not confined to ordnance equipment. The gyrocompass, submarines' inertial navigation systems, and aircrafts' autopilots and horizon indicators all use gyros.



12.139

Figure 10-6.—A stable element establishes the vertical and horizontal planes.

Gyroscopic properties are not always desirable. Take, for example, an aircraft which has high speed rotating components. These components will exhibit gyroscopic rigidity; still an aircraft must be highly maneuverable. Hence the rotating components are installed so that their rigidity has the least effect on the aircraft maneuverability.

RIGIDITY

As you know, a gyroscope is a spinning body that tends to keep its spin axis rigidly pointed in a fixed direction in space. What do we mean by FIXED DIRECTION IN SPACE? A fixed direction on earth is by no means fixed in space, because the earth turns once on its axis every 24 hours. It makes a complete revolution around the sun every year. And the sun itself is moving, taking the earth and the other planets with it. Because of these motions, the expression "fixed direction in space" as used here is theoretical. If that were an exact statement, our universe would have to be unaccelerated and therefore nonrotating. But for all practical purposes we can say this: A line from the earth to a distant star is a fixed direction in space (fig. 10-7). If the spin axis of a spinning gyro is pointed at a distant star, it will remain on the star as long as no external torque is applied to the gyro.

Any rapidly spinning body has the property of rigidity. A wheel spinning on its axis is in effect a gyro, and offers resistance to any attempt to tilt it from whatever position it has assumed in space.

The gyro rotor is not rigid as we think of rigidity in terms of a building or a tree. It can be moved in several ways. That is to say, it can be moved freely from one place to another with the gyro offering little or no resistance so long as the movement is parallel to or perpendicular to the plane of the spin axis. This is called translation. In translation no attempt is made to change the spin axis. On the other hand, when we have a rotor spinning on an axis and we try to tilt it, it offers resistance, and this resistance is in proportion to the effective weight of the spinning body and the speed at which it is spinning.

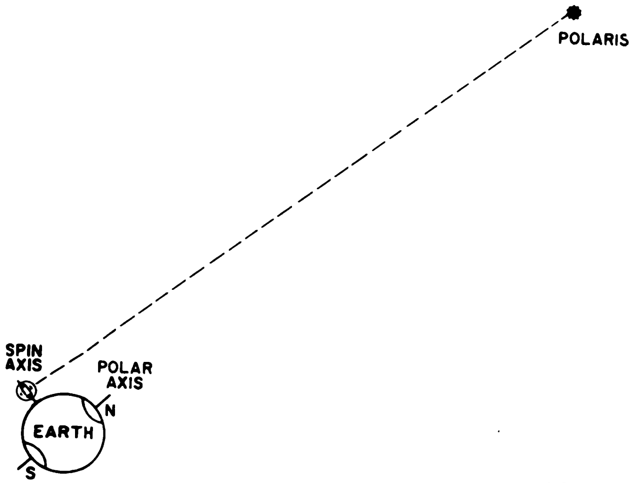


Figure 10-7.—A gyro on the earth pointing in a fixed direction in space.

Three factors determine a gyro's rigidity, or the strength with which it resists any external force tending to displace its rotor spin axis. These factors are: Weight of its rotor, distribution of this weight, and rotor speed.

We can consider the gyro as an enclosed mechanical system. The energy in the system is equal to the input energy. Hence the torque necessary to spin the gyro rotor is contained in the rotor as angular momentum. Momentum is the energy in a body due to its velocity. The heavier the gyro rotor, the larger the torque necessary to spin it, and the greater the angular momentum of the rotor. If we have two rotors with identical shapes but of different weights spinning at the same velocity, the heavier of the two will be more rigid in its spin axis since it contains the greater angular momentum and, as will be explained next, the greater inertia.

To understand the effect of weight distribution in a rotor of a gyro, consider two rotors of the same weight, with the diameter of one, half that of the other. Now, when we spin both of these rotors at the same speed, we find that the rotor with the greater diameter is much more rigid than the one with the smaller diameter. Next we find that we can make both rotors equally rigid by causing the rotor with smaller diameter to spin faster than the larger rotor. Thus rigidity is dependent upon both speed and distribution of weight. The weight of the larger rotor being farther away from the axis of spin causes it to be more effective for rigidity. In physics it is said that the weight of the larger diameter rotor has the greater "moment of inertia." What is moment of inertia? First, let's consider inertia.

INERTIA is a fundamental property of matter. Nothing in nature will start or stop moving by itself. Some external force must be applied to it first. For example, you have felt the tendency to fall backwards while standing in a bus which started suddenly. What happended was that your body tended to remain stationary but your feet were carried forward with the moving bus. From this experience you can come to the conclusion that when a body is at rest it will tend to remain at rest. After you regained your balance and your body started moving at the same speed and direction as the bus, everything was fine. Fine that is until the driver suddenly stopped the bus. Again you lost balance and tended to fall forward. In this case your body tried to continue in the direction in which the bus was traveling, but your feet were retarded by the stopping bus. From this experience we can conclude that a body in motion will tend to follow in the same straight line or direction unless acted upon by some external force. The two experiences mentioned are examples of Sir Isaac Newton's first law of motion which states: A body at rest remains at rest, and a body in motion continues to move at a constant speed along a straight line, unless the body is acted upon in either case by an unbalanced external force. Newton's first law of motion applies equally well to rotating bodies. Consider for a moment the spinning rotor of a gyro. Every particle of matter in the gyro rotor is trying to move in a straight line; but the circular structure of the wheel prevents this, and pulls them all into a circular path. The particles keep trying, nevertheless,to stay in as straight a line as possible. Consequently the rotor keeps rotating in the same plane unless acted upon by some outside force. If no external forces are present, the wheel will not move from its plane or rotation. Common sense tells us that if this is so, the spin axis must remain fixed.

Moment of inertia is a measure of the torque needed to bring about a change in the motion of a rotating body. Moment is defined as the tendency of energy acting on a body to produce motion, while inertia is the tendency of a body to resist a change in motion.

MOMENT OF INERTIA can be demonstrated with two weights — one heavy and the other light, a board, and a fulcrum, arranged in the manner of a seesaw. To balance the two weights, we have to place the heavy weight near the center and the light weight near the end of the board. This makes the light weight more effective by being farther out from the fulcrum and having greater leverage. If we have two equal weights, we can make one outbalance the other by putting one farther out on the board. The same principle applies to two rotors of equal weight, the rotor having its weight distributed "farther out on the board" has the greater moment of inertia. Its weight is more effectively placed and makes the wheel more rigid in space.

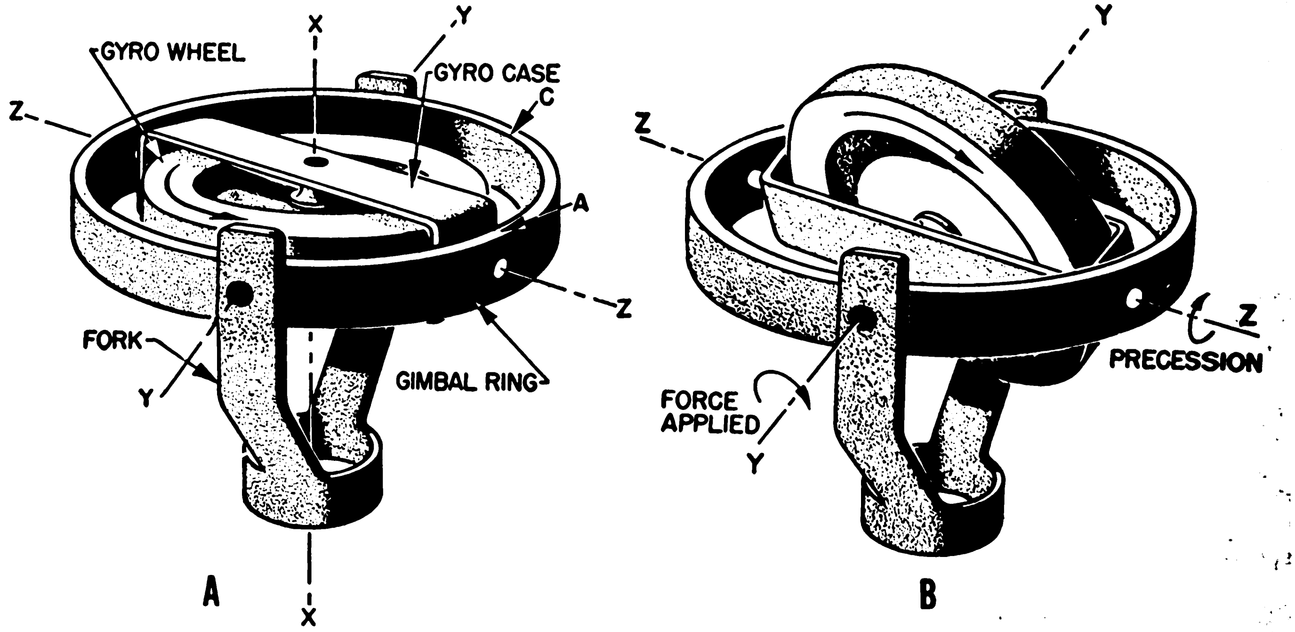
Now we can conclude that gyro resists any tilting force, and that the amount of resistance depends upon the weight, distribution of the weight, and the speed of the rotor. If we were to design a gyro for maximum resistance to an external force we would make it as heavy as possible, put as much weight as far as possible from the center of rotation, and spin the gyro wheel as fast as possible. As long as the gyro and gimbal bearings were frictionless and the center of gravity of the wheel was at the intersection of the three major axes, no displacement of the support of our perfect gyro could change the position of its rotor in respect to space. This property of a gyro is variously called rigidity, rigidity in space, rigidity of plane of rotation, gyroscopic inertia, or stability, to name a few of the more common terms. All of these terms mean the same thing.

PRECESSION

A gyro is a true space device in regard to its ability to maintain its axis in a fixed direction. To provide useful information its spin axis must be related to some reference, usually the earth's surface. This is done by using the second fundamental property of a gyro—precession. The gyro is precessed until its spin axis is pointed in the desired direction. So far we have covered precession in very general terms.

Let's consider this action in more detail by relating it to a specific equipment which we'll refer to as a basic stable element. As a FTM you will not come in contact with this particular stable element, for it is used in gun fire control systems. Due to its simplicity however, it lends itself to illustrating the factors which must be considered in stable element operation. Later in this chapter, we will discuss the Mk 16 stable element with which many of you will be involved.

Precession can be shown very plainly by using the models shown in figure 10-8, which resemble



12.14

Figure 10-8.—Gyro action: A. Gimbal mounting; B. Precession.

the basic stable element gyro and its gimbal mounting. A gyro wheel (rotor) is mounted so that it is free to align its spin axis in any direction. Here the wheel rotates in a flat loop called the gyro case (in some applications it is called the inner gimbal). The gyro case is pivoted in a ring—the gimbal ring—and the gyro can swing about the Z axis. The gimbal ring itself turns on pivots which connect it to the fork (support), permitting the gyro to tilt from side to side. This type of mounting is called a GIMBAL MOUNTING. Regardless of how the fork is placed, the spinning gyro wheel is free to lie in any given plane. That's why it is called a free gyroscope in this mounting.

To show the effect of precession, push down on the gimbal ring at point A at the nearer end of the z-z axis (fig. 10-8A). You would expect the ring to tilt around the y-y axis.

But here's the surprise—instead of rotating about the y-y axis as you might expect, the gyro case will turn about the z-z axis. You can see the effect of precession in figure 10-8B.

Similarly, going back to figure 10-8A, suppose you push sideways on the top of the x-x axis (the spinning axle of the gyro), trying to rotate the wheel around the z-z axis. Then, instead of rotating about the z-z axis, the gimbal ring will turn around the y-y axis.

If you push down at point C on the gimbal ring (fig. 10-8A), midway between the y-y and z-z axes, you will find that the gimbal ring rotates around the y-y axis, and that gyro case rotates around the z-z axis. The total effect causes the gyro wheel to turn around a line lying from point C through the center of the gyro wheel.

Now for the next question: In which direction will the gyro precess? There's a simple rule that tells you. It depends on the direction of SPIN of the gyro and the direction of the applied FORCE.

Here's a rule that applies to all spinning gyros: THE GYRO WILL ALWAYS PRECESS AT RIGHT ANGLES TO THE DIRECTION OF THE APPLIED FORCE.

Look at figure 10-8A again. If you keep pushing down on the gimbal ring at point A, the gyro case will keep turning until the axle of the gyro wheel is horizontal. Then there will be no further precession. At that point the gyro wheel is spinning in the same direction in which the applied force is pushing.

Here's another rule: A GYRO ALWAYS PRECESSES IN A DIRECTION TENDING TO LINE ITSELF UP SO THAT ITS ROTOR SPINS IN THE SAME DIRECTION THAT THE APPLIED FORCE IS TRYING TO TURN IT. In other words, the spin axis chases the torque axis. When the two come into coincidence, precession no longer takes place.

Be sure you understand that most forces, when applied to the gyro mounting, do not cause precession. For instance, you can swing the fork around in any direction, and the motion will merely be taken up in the y-y and z-z axes. Similarly, a force applied lengthwise along one of the axes will have no effect. ONLY THOSE FORCES TENDING TO TILT THE GYRO WHEEL ITSELF WILL CAUSE PRECESSION. Thus you can see that if the base of the fork were attached to the deck of a ship, the gyro would have no tendency to precess as the ship rolled and pitched.

Let's consider further the important characteristic of gyroscopic precession, using another method to illustrate this fundamental property. As you know, the rigidity of a gyroscope may be increased by making the wheel heavier, by causing it to spin faster, or by constructing it so that a larger portion of its weight is concentrated near the circumference. As it is impossible to make bearings entirely free of friction, in most gyros friction is kept to a minimum, and the rotors are designed to have a great deal of rigidity. Whatever friction remains is small in comparison to the great rigidity of the heavy, rapidly spinning rotor, in that its effect upon the operation of the gyro is extremely slight.

An operating gyro will resist a force which attempts to change the direction of its spin axis, but it will move in response to such a force or pressure. The movement is not a direct one in response to the force; it is a resultant movement. The gyro axis will be displaced, not in the direction of the applied force, but in a direction at right angles to the applied force, and in such a way as to tend to cause the direction of the rotation of the rotor to assume the direction of the torque (rotational effect on a body, a twisting effect) resulting from the applied force.

For a given force, the rate of precession is governed by the weight, shape, and speed of the wheel. These factors are the same as those that determine the rigidity of a gyroscope. Therefore, it is reasonable to assume that there is a relationship between the rigidity of a gyroscope and the rate at which a given force will cause it to precess. Such a relationship does exist. The greater the rigidity of the gyroscope, the more difficult it is to cause precession, and the less the precession for a given force will be.

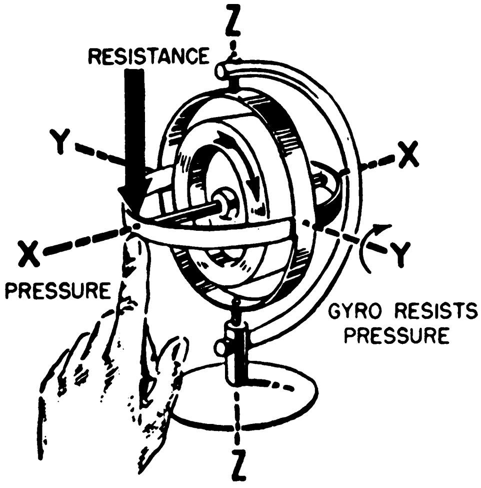


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Figure 10-9.—Force applied to a gyro.

The direction of precession in response to an applied force depends upon the direction in which the rotor is spinning. The precession is in such a direction that the wheel turns, through the smaller distance, toward a position in which the force would be acting about the spinning axis, in the direction of the spin.

The forces acting on a gyroscope may be represented graphically as acting on the rotor itself, spinning freely in space, with a plane containing each of the axes of freedom.

For example, when a force is applied upward on the inner gimbal, as shown in figure 10-9, the force may be visualized as applied in an arc about axis y-y until it contacts the rim of the rotor as in figure 10-10A. The effect produced by the force is equivalent to that produced by a force applied upward to the inner gimbal. The force is opposed by the resistance of gyroscopic inertia, preventing the rotor from being displaced about axis y-y. With the rotor spinning clockwise, the precession will take place 90° ahead in the direction of rotation at P, as in figure 10-10A. The rotor turns about axis z-z in the direction of the arrow at P, as in figure 10-10B.

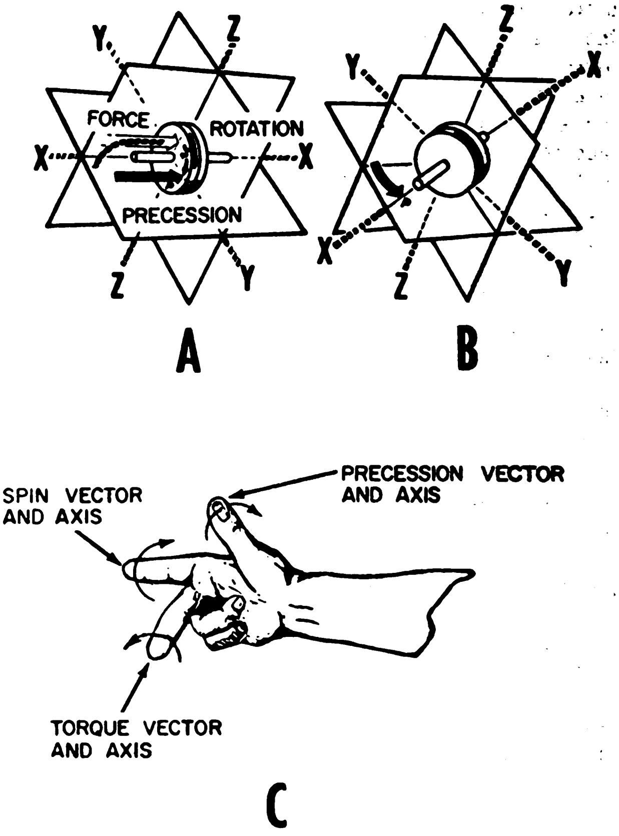

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Figure 10-10.—Rules of precession: A. Direction of precession; B. Precessional movement; C. Hand rule to determine direction of precession.

HAND RULES

The motions of a gyroscope can be analyzed by three basic vector quantities: (1) Spin, the angular velocity of the gyro rotor, (2) Torque, the rotary motion applied to change the direction of the rotor axis, and (3) Precession, the resulting angular velocity of the rotor axis when torque is applied.

All three motions are rotary (angular) and can be represented by vectors which point in such a direction that when looking in the direction of the vector the rotary motion is clockwise.

A convenient rule for determining the direction of procession is by the use of the fingers of the right hand. This method will not be new to you because you used a similar means to demonstrate the motion of a conductor in a magnetic field when you studied Basic Electricity, NavPers 10086-B.

The three vectors listed above may be represented by arranging the thumb, forefinger, and middle finger of the right hand mutually perpendicular as shown in figure 10-10C. The thumb points in the direction of the precession vector, the middle finger points in the direction of the torque vector, and the forefinger points in the direction of the spin vector. You can consider these vectors as the axes about which angular motion takes place. If you look in the direction of the pointed fingers and thumb you can visualize that all the rotary motions are clockwise as indicated in figure 10-10C.

The three finger rule is useful for analyzing any gyroscope motion problem because if the directions of any two of the three vectors are known, the direction of the third vector can be found. Thus, the rotary motion around this vector may be determined, for facing in this direction the rotary motion is clockwise.

Another hand rule determines the direction of the spin vector. Curve the fingers of the right hand in the direction in which the rotor is turning, as if you intended to grasp it. The thumb will point in the direction of the spin vector. A similar rule will give you the direction of the torque vector. With the fingers of the right hand wrapped in the direction of the applied torque (the direction the gyro would rotate if the rotor were not spinning) the thumb points in the direction of the torque vector.

DEGREES OF FREEDOM

A gyro can have two different degrees of freedom, depending upon the number of gimbals in which it is supported and the way the gimbals are arranged. You must not confuse the term "degrees of freedom" with an angular value such as degrees of a circle. The term as it is applied o gyros is an indication of the number of axes about which the rotor is free to precess.

A gyro mounted in two gimbals usually has 2 degrees of freedom. When two gimbals are mployed it is said to be universally mounted. This arrangement provides two axes about which he rotor can precess. These two axes and the pin axis intersect at the center of gravity of he rotor which is also the center of gravity of he entire system (excluding the support). Thus he force of gravity does not exert a torque to ause precession. The rotor, inner gimbal, and uter gimbal are all perfectly balanced about he three principal axes. Actually it is impos-ible to have absolute freedom about them be-ause even the most perfect bearings have some riction. But friction can be reduced to such a egree that it is slight in comparison to other actors. The gyro is capable of assuming and maintaining any position in space. Consider a rubber ball in a bucket of water. Even though the ball is supported by the water, it is not restricted as to attitude by the water but can lie in any attitude. If such a gyro were mounted in a ship, director, or a guided missile, it would not be affected by any of their movements. It would float inside its mountings much as the rubber ball floats in a bucket of water.

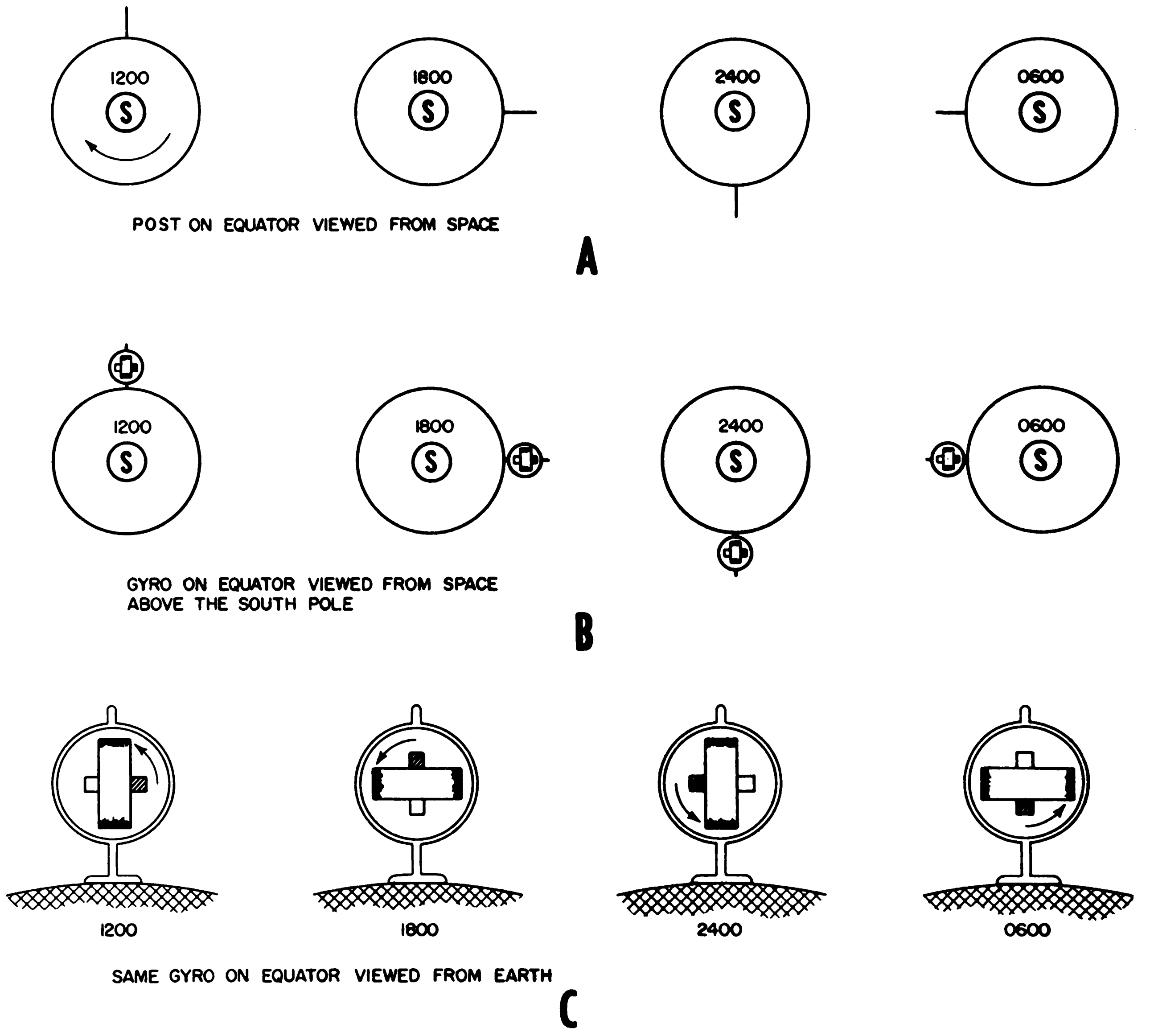
A gyro enclosed in one gimbal usually has one degree of freedom, freedom of movement back and forth at a right angle to the spin axis. You shown know something about the application of gyros in a guided missile, so let's put one of these one-degree-of-freedom gyros in a missile and observe its operation. We will mount it so that its axis of spin is parallel to the axis of travel of the missile. It is mounted now much like the flywheel in an automobile. It is spinning, and we have mounted it so that it can swing right to left. We can say that it has one degree of freedom. If the missile should nose up or down, the gyro would be forced to move exactly as the missile does (translate) in these directions. However, if the missile should turn left or right, the gyro would not change its attitude since it has freedom of motion in these directions. The spin axis would be fixed in the original direction of missile flight.

Sometimes you will read in OPs or hear about 3-degrees-of-freedom gyros. Don't let this terminology confuse you. It results from counting the spin axis as a degree of freedom.

EFFECT OF ROTATION OF THE EARTH

A free gyro maintains its axis fixed in space, and not in relation to the earth's surface. To understand this, imagine yourself in a space ship somewhere out in space and looking at the South Pole of the earth. You could see a sphere rotating clockwise, with the South Pole in the center. Maneuver your ship until it is on a direct line with the South Pole and then cut in the automatic controls to keep it in this position. The sphere you see would make a complete rotation every 24 hours.

You could keep track of that rotation by driving a big post into the Equator as shown in figure 10-11A. If this post was upright at 1200, the earth's rotation would carry it around so that it would be horizontal and pointing to the right at 1800. Likewise, the earth's rotation would carry the post around so that at 2400 it would be upside down. Then, at 0600 the next day, the post would be horizontal and pointing left. Finally


1200
S
1800
S
2400
S
0600
S
POST ON EQUATOR VIEWED FROM SPACE
A
1200
S
1800
S
2400
S
0600
S
GYRO ON EQUATOR VIEWED FROM SPACE
ABOVE THE SOUTH POLE
B
1200
1800
2400
0600
SAME GYRO ON EQUATOR VIEWED FROM EARTH
C

12.144

Figure 10-11.—Fixed direction in space: A. Post on the Equator viewed from space; B. Gyro on Equator viewed from space; C. Gyro on Equator viewed from earth.

at 1200 the next day the post would be back in its original position, having been carried, with the earth, through its complete rotation. Notice that the post has many positions as you observe it—because it is attached to the earth's surface and does not have rigidity in space.

If you put a gyroscope in place of the stake you would see a different action. Imagine, now, a gyroscope instead of a post mounted at the Equator. The gyro is spinning and DOES HAVE RIGIDITY IN SPACE. Look at figure 10-11B. At 1200 the spinning axis is horizontal with respect to the earth's surface. At 1800 the spinning axis is vertical with respect to the earth's surface; but the gyro is still spinning in the same plane as before, and the black end is pointing away from the earth's surface. At 2400, the spinning axis is again horizontal. At 0600 the spinning axis is again vertical and the black end points toward the earth. Finally, at 1200 the next day, the gyro is in the same position as when you started. In fact, the gyro wheel spinning on its axis has not changed the direction in space of its plane of spin in being carried through the whole rotation of the earth. This is because the gyro is RIGID IN SPACE.

You have just imagined observing the gyro from space. Now, let's come back to earth and stand right next to the gyro. You can't feel or see the earth's rotation—but it's rotating. Look at the gyro in figure 10-11C. From your viewpoint on earth, the spinning axis appears to make one complete rotation in one day. Actually, as you know, the gyro is rigid and both you and the earth are rotating.

Refering back to figure 10-7, the illustration of the gyro mounted on the earth's equator shows that the gyro's spin axis is parallel, not at right angles, to the earth's north-south axis.

The effect on a gyro of the earth's rotation is sometimes called APPARENT DRIFT, APPARENT PRECESSION or APPARENT ROTATION.

EFFECT OF MECHANICAL DRIFT

The spin axis of a gyro is not always in the direction in which it theoretically should point. The direction depends upon its application. In the case of a stable element the axis of spin should be vertical. Looking at it another way, the rotor should spin in a horizontal plane.

A directional error in a gyro is produced by random inaccuracies in the system caused by mechanical drift and the effect of the earth's rotation (apparent drift).

We shall see later on how it is corrected for in the basic stable element. First, let's consider the causes of mechanical drift.

There are three general sources of mechanical drift:

1. Unbalance. A gyro often becomes dynamically unbalanced when operated at a speed or temperature other than that for which it was designed. Remember that the slower the speed of a gyro the easier it is to precess. The static balance of the gyro may be upset because its center of gravity is not at the intersection of the three major axes. Some unbalance of both types will exist in any gyro since manufacturing processes cannot produce a perfectly balanced gyro.

2. Bearing friction. Friction in the gimbal bearings results in loss of energy and incorrect gimbal positions. Friction in the rotor bearings causes mechanical drift only if the friction is not symmetrical. An even amount of friction all around in a rotor bearing results only in a change of the rate of rotation.

3. Inertia of gimbals. Energy is lost whenever a gimbal rotates because of the inertia of the gimbal. The greater the mass of the gimbal, the greater the drift from this source.

The complete elimination of mechanical drift in gyros appears to be an impossibility. However, by proper design it has been kept to a minimum. Any error which still exists can be corrected for. You may be wondering why an FT cares about design. The reason for listing some of the sources of drift was to impress upon you that a gyro does have sources of error built into it. Furthermore, when you work on a gyro don't unintentionally increase these errors. An easy way to do this would be to allow dirt, a piece of solder, or other foreign matter to get into a gimbal bearing. Excessive lubrication is another source of error.

KEEPING THE GYRO VERTICAL

The simple 2-degrees-of-freedom gyroscope such as you studied in a previous section would, if set with its spinning axis vertical to the earth's surface and parallel to the direction of gravity, become a direction-indicating device. Once set, it would continue to point in the vertical as long as no disturbing forces caused it to precess from this position. Given time it will precess from the vertical. The disturbing forces or torque caused by apparent and mechanical drift are always present. To find and maintain a vertical position, or any other position, a gyro-erection system is necessary.

To make a gyroscope into a direction-indicating device and one which indicates accurately at all times, the following requirements must be met:

1. Torques must be provided of the correct magnitude and direction to precess the gyro in such a manner that the spinning axis is brought to the desired direction after the rotor has been set spinning.
2. Torques must be provided to precess the gyro back to the required position at the proper rate and direction so as to cancel the effects of apparent and mechanical drift.

The torques required to produce the proper precession to convert the gyro into a direction-indicating device are provided by an erecting system. Erection may be accomplished pneumatically, mechanically, or electrically, depending on the type of power available, and is usually activated in response to the force of gravity. Specific erection systems are many and varied. We will discuss in detail the system used in the basic stable element. When used, erection is a continuous process. Remember, once the gyro has been set spinning in the desired direction, erection is necessary only when the time the gyro is in use is long enough for the earth's rotation and mechanical drift to have effect.

Go back to figure 10-8A again, and suppose the base of the fork is fastened to the rolling and pitching deck of a destroyer. A roll of the ship tilts the fork, so as to lower the nearest prong. This SHOULD have no effect on the gyro. The gyro case should rotate on the z-z axis, and the gyro should stay vertical. But suppose there is a little FRICTION in the z-z bearings. This will exert a slight DRAG on the gyro case, tending to ROTATE the gyro about the z-z axis causing the gyro to precess AWAY FROM THE VERTICAL, about the y-y axis.

The bearings used in these instruments are nearly frictionless, but there is always enough friction to cause trouble. Over a period of time, these slight frictional forces will move the gyro a long way from the vertical.

That means you need some corrective force which will bring the gyro back to the vertical when it wanders away. This force is provided by the gyro ERECTING SYSTEM.

The most common type of erecting system consists of two tanks of mercury, fastened to opposite sides of the gyro case. The two pools of mercury are connected at the bottom by a small tube (fig. 10-12). An air tube connects the tops of the two tanks in order to prevent the formation of a vacuum.

Figure 10-12 is a schematic view of the gyro case with the gyro tilted away from the vertical. Gravity causes the mercury to run from the high tank into the low tank. Therefore the low tank becomes HEAVIER than the high tank. This sets up a force which tries to tip the gyro farther. The gyro RESISTS this force and PRECESSES to one side—tilting the top of the gyro axle toward you.

So far, not much has been accomplished toward getting the gyro back to the vertical. That comes next. Notice that the tube connecting the two tanks is rather small. Therefore the mercury flows slowly. After the case it tilted, it takes nearly a second for the mercury to find its level.

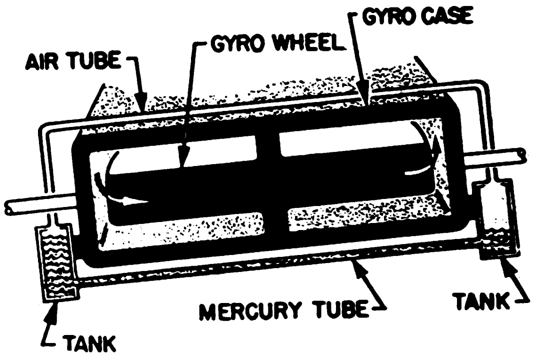


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Figure 10-12.—Mercury system on basic stable element.

At the same time, the fork is being rotated by a small motor about 18 times a minute. (Figure 10-13 is a schematic diagram of the gimbal rotation system and mercury ballistic system.) Therefore, during the time that it takes for the mercury to flow into the low tank, the fork and the entire gimbal assembly has rotated 90 degrees. As before, the weight of the mercury is trying to tip the gyro sideways, but this time 90° away from the actual tilt. Thus, the gyro precesses back TOWARD THE VERTICAL.

You will see this more clearly if you think about what happens during one rotation of the fork. The result is indicated in figure 10-14 in which you are looking straight down at the top of the gyro case and the mercury tanks. Understand that this diagram is purely schematic. It is intended to give you an idea of the principle involved, not a complete picture of what happens to a gyro in actual operation.

Suppose that the gyro spin axis is suddenly tilted toward the north at an instant when the mercury tanks are lined up north and south (fig. 10-14A). Mercury STARTS to flow into the north tank, but at first no precession occurs because of the lag or time delay in the mercury flow.

As the case rotates, the low tank is moving toward the east and is filling up with mercury.

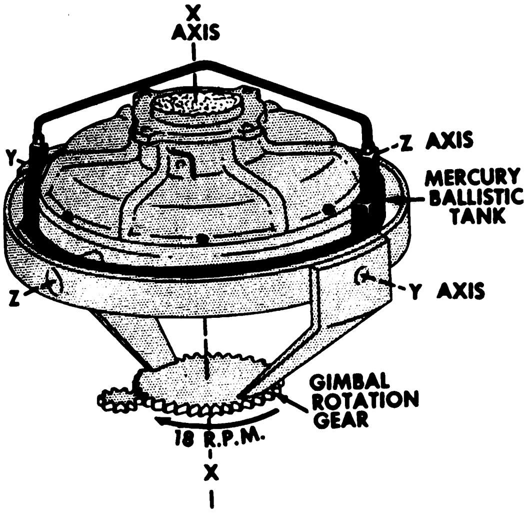

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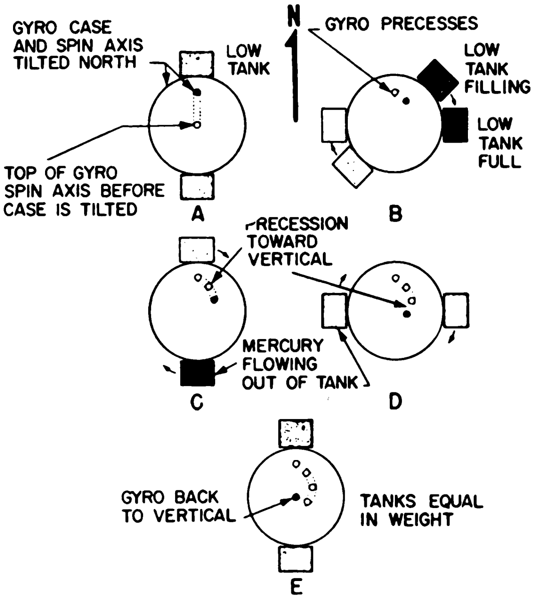
Figure 10-13. — Gimbal rotation.


GYRO CASE AND SPIN AXIS TILTED NORTH
LOW TANK
TOP OF GYRO SPIN AXIS BEFORE CASE IS TILTED
A
N
GYRO PRECESSES
LOW TANK FILLING
LOW TANK FULL
B
PRECESSION TOWARD VERTICAL
MERCURY FLOWING OUT OF TANK
C
D
GYRO BACK TO VERTICAL
TANKS EQUAL IN WEIGHT
E

12.147
Figure 10-14. — Effect of rotating the fork.

As the lower tank fills, the gyro begins to precess faster and faster in a generally southeasterly direction. By the time the low tank is FULL, it is headed east (fig. 10-14B) and the gyro is precessing rapidly south.

Continued rotation puts the loaded tank on the high side, and the mercury begins to flow out of it (fig. 10-14C). But the tank is still heavy and therefore the gyro precesses generally southwest (fig. 10-14D). By the time the tanks are again lined up north and south, the mercury in the two tanks has equalized (fig. 10-14E). The second tank is now the low tank. It begins to fill up, and the entire process repeats.

You can see that the easterly and westerly precessions tend to cancel. The net effect is a precession toward the south, bringing the gyro BACK TO THE VERTICAL.

Thus, you can see that whenever the gyro is started, the mercury system will bring it quickly to the vertical. And at any time the gyro wanders off the vertical, the mercury system will bring t back.

If you were able to observe the starting of the basic stable element, you would notice that at first he gyro would precess rapidly towards the vertical. But you would also notice that the erecting system may require as much as 10 minutes to correct the last few minutes of error. This is because as the gyro comes nearer to the true vertical, less mercury flows from one tank to the other during a rotation of the gimbals. Consequently the precessional force is small and the rate of precession is very slow. In some gyro systems — the master gyro compass, for example — it may take as long as 24 hours for the gyro to finally settle down in its true position.

Let's review the main purposes of the gimbal-erecting system of a stable element. First of all, it brings the gyro to the true vertical when the gyro is started. Second it compensates for the effect of friction and other irregularities in the gimbals which could cause the gyro to precess away from the vertical.

There are several other types of erecting systems used with gyros. If you are in doubt about the mercury system, go back over the text, for it is the basic erecting system of modern fire control gyro stabilizers.

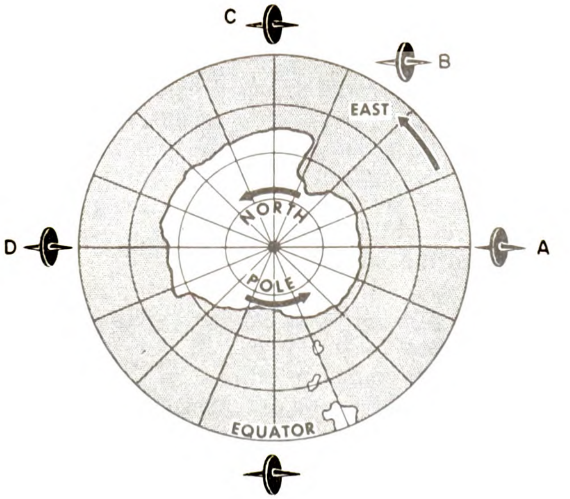
Latitude Correction

A few pages back we mentioned that there are two kinds of action which tend to pull a gyro out of the vertical. One of these is the random effect of bearing friction and other similar irregularities. You have seen how a mercury erecting system overcomes this effect.

In addition to these random actions, the ROTATION OF THE EARTH has a continuous effect on the gyro. Remember that gyroscopic stability (also called rigidity of plane) means that a gyro axle tries to maintain a fixed direction IN SPACE. But the earth, as it rotates toward the east, is rolling under the gyro. Therefore, to an observer standing on the earth, the gyro appears to keep tipping westward. Apparent rotation was described in an earlier article and effect was observed from a position over the South Pole. Let's reverse our position and look at the effect of the earth's rotation.

This effect appears clearly in figure 10-15. The figure is a view of the earth as it would appear if you were looking down on the North Pole. Imagine that a gyroscope has been erected on the Equator at Point A with its axis vertical (Perpendicular to the surface of the earth), and that because the gyroscope has frictionless bearings and no erecting system you must rely on gyroscopic stability to keep it vertical. After a few hours, the rotation of the earth will move point A to the position marked B.

The gyro still heads in the same direction in SPACE, but it is no longer VERTICAL. Its axis is no longer perpendicular to the earth's surface at that point. To anyone standing on the earth, it appears to be leaning to the west. After 6 hours, when the earth has made a quarter turn, the gyro will be horizontal, as at C. After 12 hours (at position D) it will have turned completely over and will be upside down. And after 24 hours, the gyro will have made a complete revolution.



12.148

Figure 10-15.—Apparent rotation at the equator.

In other words, the gyro is tilting WESTWARD at a rate of 15° per hour.

The mercury-erecting system of the stable element won't quite prevent all of this tilt. The gyro, therefore, must be made to precess EASTWARD at 15° per hour.

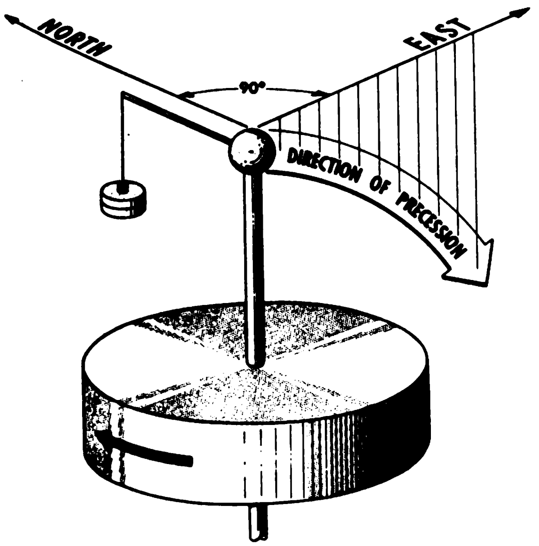
Now when the gyro is truly vertical, the mercury system causes no precession. The mercury affects the gyro only when the gyro is tilted. And so, if we were to rely on the mercury system to produce the required eastward precession, the gyro would always lean slightly to the west. It would NEVER be truly vertical, as it should be for efficient fire control. An error would always persist, being maximum at the Equator, and gradually decreasing to zero at either pole.

When a gyro is vertical, therefore, you correct for the effect of the earth's rotation at all times by applying to the gyro some force that will cause a steady eastward precession. This means that in dealing with Navy stable elements the top of the gyro axle must be pushed northward.

This can be done by extending a small arm northward from the top of the axle, and by hanging a weight on the north end of the arm, as in figure 10-16. The weight will keep trying to tip the axle northward, and this will cause an eastward precession.

Up to now, it's been assumed that the gyro is located at the Equator. A little thought will show you that if the gyro were placed at the North or South Pole, the rotation of the earth would have no tendency to move it out of the vertical. The gyro's axis is parallel to the earth's axis. Apparent rotation is about the gyro's spin axis and no effect will be observed. So you would expect that at points on the earth between the Equator and the Pole, the gyro would tilt westward at a speed LESS than 15° per hour. This is true, and figure 10-17 shows you why. If a gyro is set vertical at A, it will move to point B in 12 hours, and will tilt through an angle of 180° minus 2 x latitude of A (instead of through 180° as it would be at the Equator).

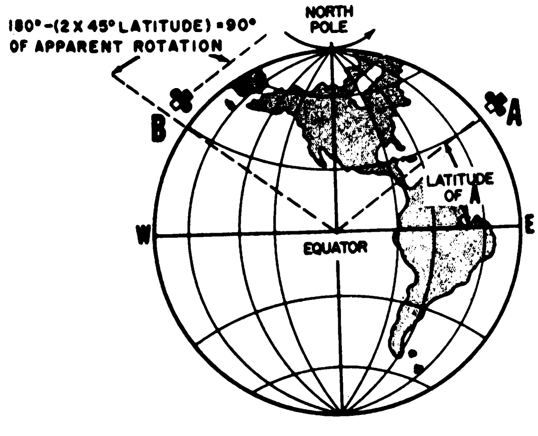
This means that the precessional force should be decreased in higher latitudes. You can slow



12.149
Figure 10-16.—Latitude correction weight.

down the precession by moving the compensating weight inward on the arm, closer to the gyro axle. The arm has markings on it to show you the correct position of the weight for any latitude (fig. 10-18). The weight is called the LATITUDE-CORRECTION WEIGHT.

Figure 10-18 shows the appearance of the gyroscope and its case. Notice, in the cutaway portion, that the GYRO WHEEL is the rotor of a 3-phase a-c induction motor. The case forms the motor stator. This gyro-driving motor is operated by 70-volt 146-Hertz (Hz) a-c obtained from a special MOTOR GENERATOR set. The 146-Hz current is used in order to permit high gyro speeds. The maximum speed which can be obtained from 60-Hz current with an induction motor is only 3,600 RPM, but 146 Hz permits nearly 146 times 60, or 8,760 RPM.



12.150
Figure 10-17.—Effect of earth's rotation at midlatitudes.

Different systems use different types of erecting systems. However, the mercury gimbal-erecting system is common. You will learn another type later in this chapter. But no matter what type of gyro-erecting system you encounter, its basic purpose will be the same. It helps the gyro to find and maintain a vertical position, which is used in developing roll and pitch signals for your fire control system.

If you learn the basic gyro theory, the rest is easy. No matter how the gyro is used, it will always display the same familiar characteristics —RIGIDITY OF PLANE OF ROTATION, AND PRECESSION.

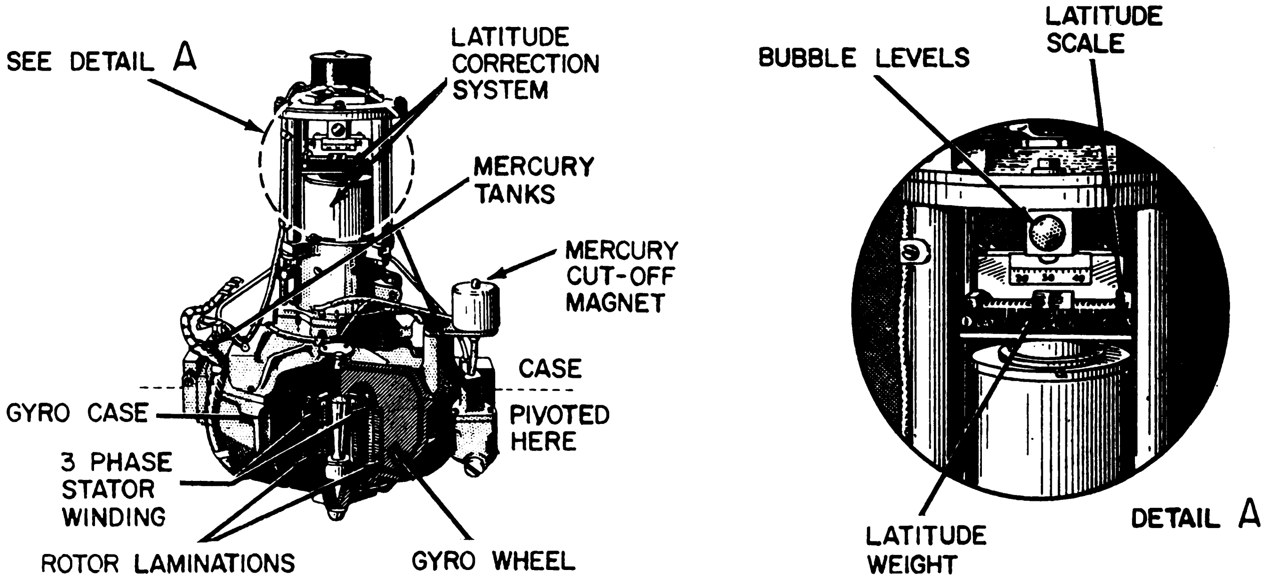
The free gyro in the stable element maintains its spin axis vertical with respect to the earth, and not space. Gravity acting on the erecting system causes the gyro to precess so that the spin axis is always in the vertical plane. In other words, the gyro tracks the local vertical by using its property of precession.

DETERMINATION OF PITCH AND ROLL

The fact that the ship rolls and pitches about a gyro has no value unless you can convert their relative position into a mechanical or electrical representation. Our basic stable element will accomplish this by means of an electromagnet and two figure-eight coils (fig. 10-19).

On top of the gyro assembly is mounted an electromagnet which is energized by 115-V a.c. An umbrella which supports two sets of figure-eight coils, one for pitch and one for roll, is mounted on the pitch gimbal.

When the ship is not moving, the magnet points directly at the intersection of the lines on the umbrella. The voltages induced in the two figure-eight coils are equal and opposite. The signal output is therefore zero. But if the ship is tilted,



12.151

Figure 10-18.—Gyro case of the stable element.

the gimbal assembly and fork roll around the gyro, and the magnet points at some other point on the umbrella. This produces an output signal voltage in the umbrella coils. This voltage is then amplified and fed to a set of electric followup motors (one for pitch and one for roll). The followup motors reposition the pitch and roll gimbals so that the center of the umbrella is again over the magnet (fig. 10-19). In repositioning the umbrella, the followup motors have driven out the pitch and roll angles at their shafts.

STABLE ELEMENT MK 16

LEVEL AND CROSSLEVEL

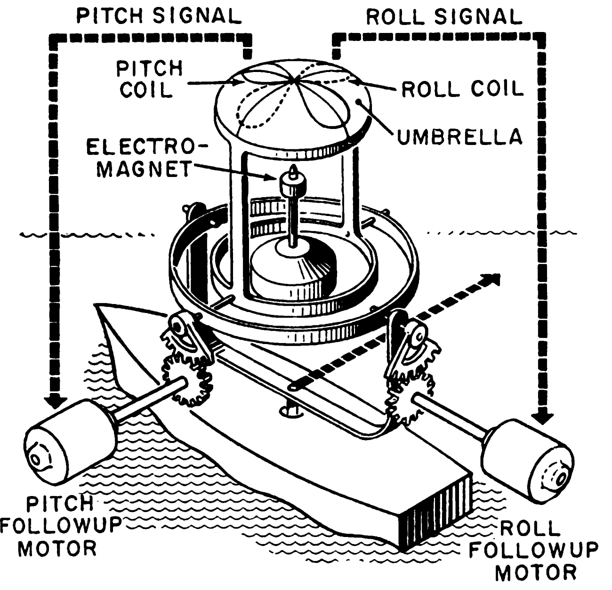
The primary purpose of the Stable Element Mk 16 is to accurately measure the deviation of ship's deck from the horizontal plane. These measurements can be made in relation to the vertical plane containing own ship's centerline or the vertical plane containing the target line of sight (LOS). If measured in relation to the vertical plane containing own ship's centerline, the angles are called roll (Zdo) and pitch (Eio). If measured in relation to the vertical plane containing the LOS, the angles are called crosslevel, (Zd) and level (Ei) (fig. 10-20).

As in our basic stable element, the heart of the Mk 16 stable element is a gyro. The gyro will measure crosslevel and level angles if the gyro gimbals are properly oriented with respect to th LOS. This orientation is maintained by positionin the gimbals through the director train angl (fig. 10-21). If the director is trained to a zer degree train angle, the vertical plane containin the LOS would also contain own ship's centerline At this time, level would be a measure of ship' pitch, and crosslevel would be a measure of ship' roll. If the gyro gimbals are locked in this positio the Mk 16 stable element will provide roll an pitch signals, which is what we are intereste in as FTMs.

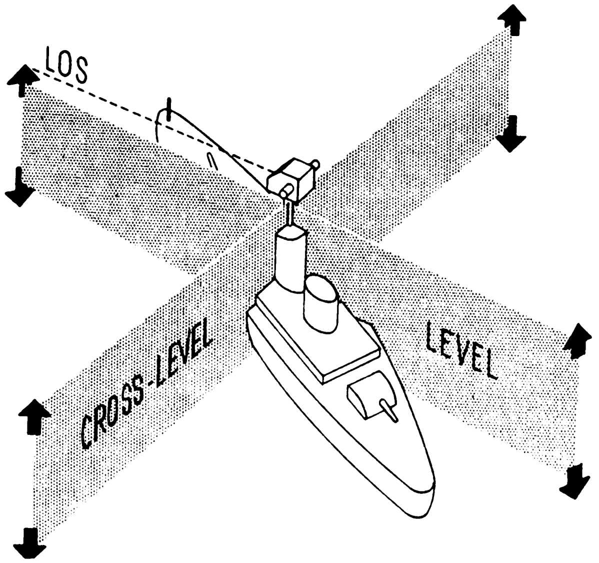
Since we are interested in roll and pitch, yo might by asking yourself, "Why all the emphasis on the level and crosslevel?" The answer lies in the fact that the equipment manuals for th Mk 16 stable element might place heavy emphas on level and crosslevel in their various explan tions of the equipment. You will not have a problem if you remember that level correspon to pitch and crosslevel corresponds to roll, the director train gimbal of the Mk 16 stab element is locked at zero degrees train.

THE GYRO

The gyro is mounted in a hermetically seale housing (fig. 10-22). The housing is filled wi



167.137
Figure 10-19.— Pitch and roll signals.



12.46
Figure 10-20.— The level and crosslevel angles are measured in respect to the LOS in vertical planes indicated by the arrows.

llium — an inert, light-weight gas that does not ratify. The gas serves to transfer heat generated the gyro to the surface of the housing. The using is held within a gimbal ring by a pair torsion wires. The gimbal in turn is held in a cond housing, called the flotation tank, by a cond pair of torsion wires. The flotation tank filled with a liquid of sufficient density at s operating temperature to float the gyro using. Therefore, the housing is suspended in state of neutral bouyancy. Consequently, the rsion wires do not carry any load, but only x the position of the housing and the gimbal the tank.

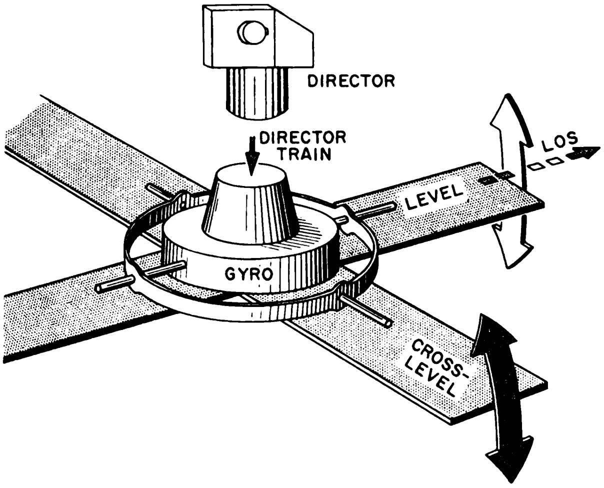
Two electromagnets are mounted on the gyro le (fig. 10-22). The position of the magnets is termined by the gyro spin axis. Two crossed-E kup coils are fixed inside the flotation tank se to the magnets so that the magnets can uce voltages in the coils. The position of the kup coils is determined by the motions of the tation tank. When the magnets (gyro spin axis) e centered on the pickup coils (top-to-bottom ference line of the flotation tank), the voltages duced are equal and will cancel each other. When coils are not centered on the magnets however, voltages induced in the coils do not cancel, d there is an output. The amplitude of the output voltage is proportional to the amount of tilt or, more exactly, to the angle between the spin axis of the gyro and the reference line of the flotation tank. The phase of the pickup coil output voltages depends on the direction of the tilt.

We know the spin axis of the gyro must be aligned with the vertical. The flotation tank is mounted in a gimbal system. Once we know the gimbal system we can develop how the gyro is brought to the vertical and how output signals from the pickup coils are used.

GIMBAL SYSTEM

In addition to the gimbal in the gyro housing there are five more gimbals: the azimuth, pitch, roll, director train, and a second roll gimbal used for alignment and test purposes. We will take them in order, starting with the innermost gimbal. The azimuth gimbal (fig. 10-23A) supports the sensitive element, two pendulums — called the run pendulums, own ship's speed resolver, and own ship's heading control transformer.

The pitch gimbal (fig. 10-23B) carries the azimuth gimbal and pivots inside the roll gimbal.



55.179
Figure 10-21.—Gimbal positioning.

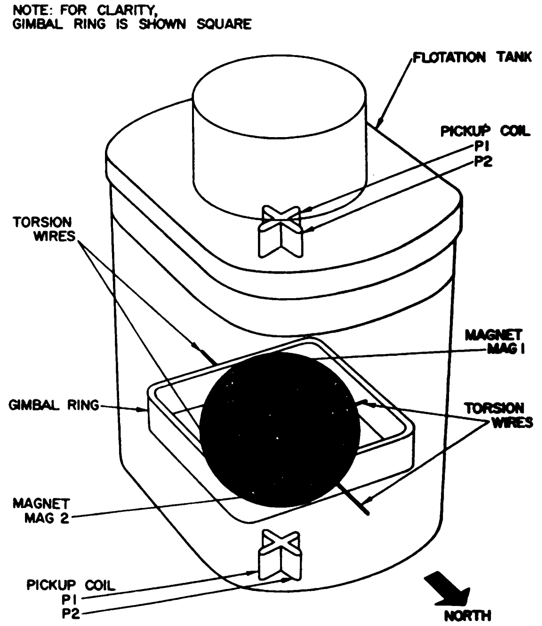
The other components carried by the pitch gimbal are: the pitch servomotor and synchros, two rapid-settle pendulums, own ship's speed servo, and a coordinate resolver.

The roll gimbal (fig. 10-23C) pivots inside the director train gimbal. Besides the pitch gimbal it carries the roll servomotor and synchros.

The director train gimbal (fig. 10-23D), which holds the three gimbals already mentioned, is supported in the binnacle or main housing by a large bearing. The bearing mounting is machined so that the plane in which the gimbal would move, if it were free to do so, is parallel to the ship's reference plane. The fire control systems measure train in this plane and elevation with respect to it. The reference plane moves with the ship's deck plane.

The second roll gimbal is pivoted on the binnacle by its gimbal bearing so that the gimbal rotation axis lies along the fore-and-aft axis of own ship. The second roll gimbal is maintained in the vertical plane by the azimuth gimbal. Two spirit levels are mounted at right angles to each other on the second roll gimbal. The spirit levels measure the roll and pitch angles, which are used for testing and aligning the stable element.

Now let's see how this elaborate gimbal system works. To start with, the director train gimbal

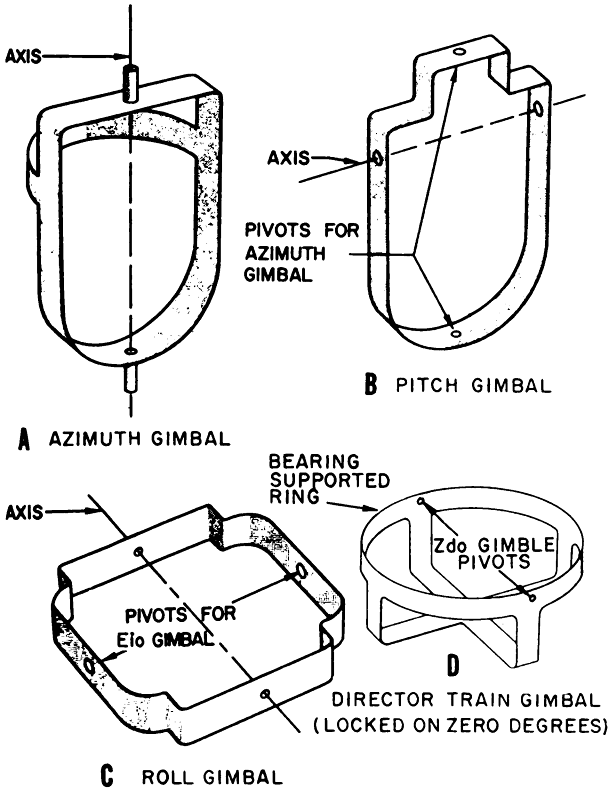


166.29
Figure 10-22.—Phantom view of sensitive element.

is locked on zero degrees so that the pitch and roll gimbal axes are aligned in and across own ship's centerline. Therefore, the movements o the pitch and roll gimbals are positioned about their axes by the pitch and roll servos. The signals to the servos are taken from the gyro pickoff coils and the run pendulums. We will consider the signal circuits later.

The pitch servo is nulled when the pit gimbal is positioned in the horizontal pla that is measured with respect to the vertic plane through own ship's centerline. The ro servo is nulled when its gimbal axis is positio in a plane perpendicular to the vertical pla through own ship's centerline. Since the pitc gimbal is supported by the roll gimbal, th position of the pitch gimbal is measured w respect to the roll gimbal or the vertical pl Therefore, the pitch gimbal is maintained in true horizontal plane. The position of the gimbal is measured with respect to the direc train gimbal, or more exactly, to the normal pla perpendicular to the deck plane.

As was brought out, the pitch gimbal maintained by its servo in the true horizon



166.30

Figure 10-23.—A. Azimuth gimbal; B. Pitch gimbal; C. Roll gimbal; D. Director train gimbal (locked on zero degrees).

lane. Since the pitch gimbal supports the azimuth imbal, its axis, which is 90 degrees from the itch axis, is pointed towards the true zenith r vertical. In other words, the azimuth gimbal s stabilized by the pitch and roll gimbals. nd it follows that the flotation tank is also tabilized in the vertical plane.

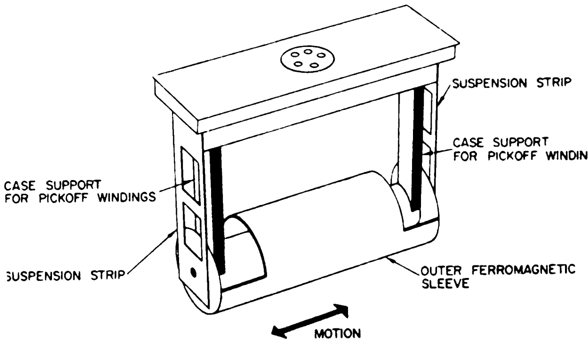
The azimuth gimbal is positioned by own-ship eading servo. Therefore, the gyro pickup coils nd the run pendulums have a fixed position with espect to the N/S axis. This arrangement mplifies the introduction of the correction to ompensate for apparent tilt that is made to the ermetically sealed gyro. But it requires coordi- te conversion of the signals that originate the azimuth gimbal system and are used in e pitch and roll servos. The coordinate resolver the pitch gimbal rotates the N/S and the E/W gnals to proportional signals related to own ip's centerline.

ERECTING PROCESS

When the stable element is started, the gyro spin axis is brought to the vertical plane by two sets of pendulums, the run pendulums and the rapid-settle pendulums. The run pendulums are mounted on the azimuth gimbal, arranged at right angles to each other, one along the N/S axis, and the other along the E/W axis. The rapid-settle pendulums are mounted at right angles to each other on the pitch gimbal. One pendulum is aligned along own ship's centerline, the other across own ship's centerline.

Basically, the pendulums consist of a concentrated mass, called a bob, supported by a flexible suspension strip (fig. 10-24). Pendulum construction limits the motion of the bob to one plane. The bob can move along the axis supported by the flexible strip. Hence, if the pendulum mounting is tilted along the pendulum's sensitive axis the bob will move. The amount of motion is determined by the unbalanced force, which is proportional to the degree of tilt of the mounting. The direction of the bob's motion is determined by the direction of the tilt.

Pendulum motion produces electrical signals proportional to the tilt of the gimbal. These signals are used to drive the pitch and roll gimbals until the signals are nulled. The run pendulum signals along the N/S and E/W axes are converted to the pitch and roll axes and then combined with the signals from the rapid-settle pendulums. The pitch and roll gimbals stabilize the azimuth gimbal in the vertical. Because the gyro tends


SUSPENSION STRIP
CASE SUPPORT FOR PICKOFF WINDINGS
CASE SUPPORT FOR PICKOFF WINDINGS
SUSPENSION STRIP
OUTER FERROMAGNETIC SLEEVE
MOTION

166.31

Figure 10-24.—Main pendulum without case, simplified.

to remain fixed in space as the servomotors drive the gimbals, the torsion wires of the gyro suspension system become twisted and exert torque on the gyro. The gyro will precess at right angles to the applied torque and its spin axis will follow a spiral path to the vertical.

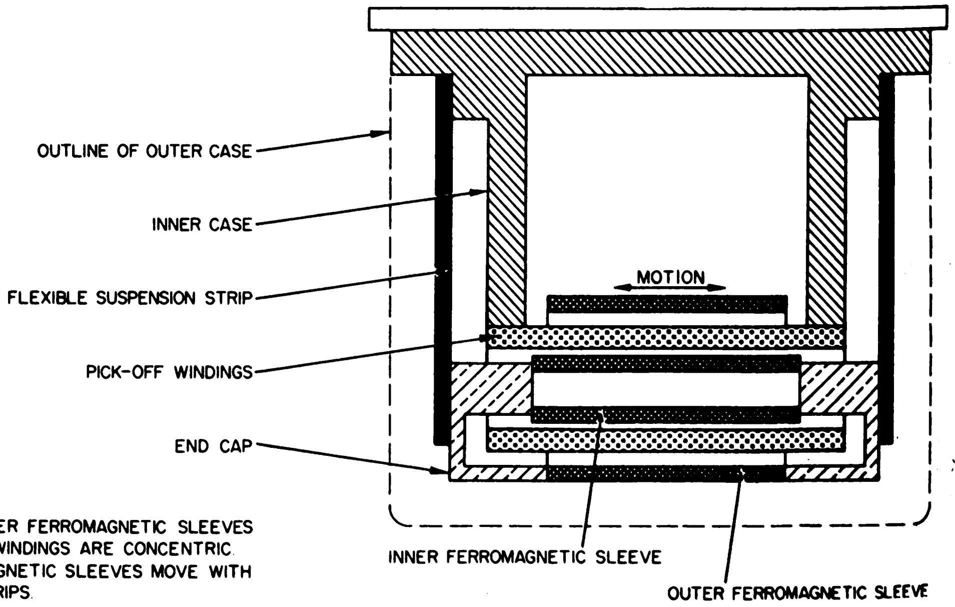
The run pendulums are the vertical seeking devices of the stable element. When the gyro spin axis is in the vertical, only half of the output signal strength from the run pendulum is used. But during the stable element's starting period the entire signal is used. The run pendulums are heavily damped to reduce the effects of ship's maneuvers. Therefore, the rapid-settle pendulums, which are lightly damped, are used to help bring the gyro to the vertical rapidly. Once the gyro is settled in the vertical the rapid-settle pendulum circuits are deenergized and these signals are eliminated.

RUN PENDULUM CIRCUIT

Figure 10-25 shows a simplified cross-sectional view of a run pendulum. The inner and outer ferromagnetic sleeves and the windings are concentric. When the pendulum is tilted, only the sleeves move with the suspension strip. The sleeves form the core of the pickoff windings and pivot about them.

Figure 10-26 shows a simplified signal circui of a pendulum. The core of the pickoff windin (terminals 5 and 6), is the pendulous ferromagneti sleeve. The two sections of the pickoff windin are wound in opposite directions. The othe winding (terminals 1, 2, 3, and 4), is an autotransformer. The sections of the transformer ar wound in the same direction. The two sections o the pickoff winding and terminals 1, 2, and 3 o the transformer are connected to form a bridg circuit. A 12-volt excitation is applied t terminals 2 and 4. Disregarding own-ship ac celeration effects and corrections, the bridg circuit develops no voltage output across the loa resistor when the azimuth gimbal is vertical because the run pendulum bob is vertical and th core is centered in the pickoff winding.

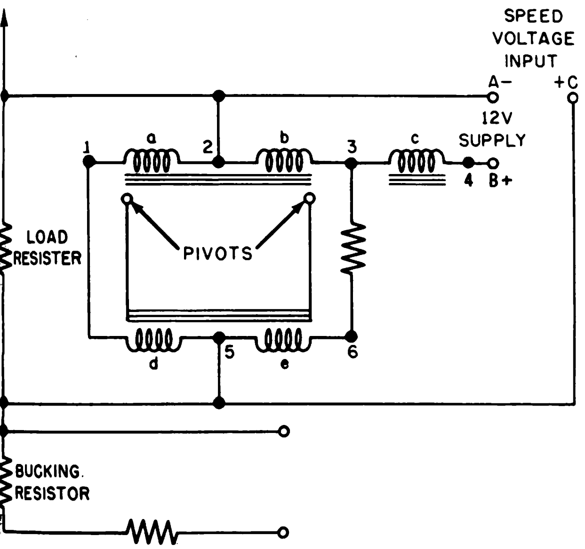
When the azimuth gimbal is tilted, th pendulum core moves, the bridge balance is dis turbed, and a voltage is developed across t load resistor. When the core pivots off cent the reluctance in the section of the winding th


OUTLINE OF OUTER CASE
INNER CASE
FLEXIBLE SUSPENSION STRIP
PICK-OFF WINDINGS
END CAP
MOTION
INNER FERROMAGNETIC SLEEVE
OUTER FERROMAGNETIC SLEEVE

NOTE
INNER AND OUTER FERROMAGNETIC SLEEVES AND PICK-OFF WINDINGS ARE CONCENTRIC. ONLY FERROMAGNETIC SLEEVES MOVE WITH SUSPENSION STRIPS.

166.

Figure 10-25.—Cross section of main pendulum, simplified.



166.33

igure 10-26.—Pendulum bridge and force motor circuit, simplified schematic diagram.

ost some of its core will increase, and the oltage in that leg of the bridge circuit will ecrease. At the same time the reluctance of the ickoff winding gaining core surface will decrease nd the voltage in that leg will increase. The agnitude of the voltage depends upon the amount f core displacement from the center of the pickff winding. The phase of the voltage, with eference to the excitation voltage, is determined y the direction of the core displacement.

The output signal of the run pendulum bridge ircuit is proportional to the tilt of the azimuth imbal. There are two run pendulums, with entical bridge circuits. The output signals are elated to gimbal tilt in the N/S and E/W axes f the earth. Thus these signals have common es with the signals from the gyro pickoff coils. nce the azimuth gimbal supports the flotation nk, both sets of signals are a measure of the lt of the gimbal out of the vertical. Remember, e gyro spin axis is rigid; however, gyro preession is 90 degrees away from the torque plied by the torsion wires. Therefore, the N/S n pendulum signal is combined with the E/W ro pickup signal. Let's look at this fact a little oser.

The run pendulum signal is determined by e force of gravity, but the pendulums are heavily damped. Obviously, their reaction to a tilt of the azimuth gimbal is relatively slow. On the other hand, if the azimuth gimbal, and therefore the flotation tank, is tilted, the pitch and roll servos will react instantly and reposition the azimuth gimbal back to the vertical. Therefore, the signals from the gyro pickup coils are the primary control to stabilize the azimuth gimbal when the ship's deck is tilted.

SHIP'S ACCELERATION CORRECTION

When the ship is accelerated by either a course or speed change, inertia causes the bobs of the run pendulums to tend to lag behind their pivot points. The degree of lag is determined by the ship's acceleration rate and direction of ship's travel. If this is not counteracted, the pendulums are not a true vertical reference for the gyro during ship accelerations.

Compensation for ship acceleration is made by using the run pendulum pickoff winding as a force motor to control the position of its pendulum sleeve. The winding forces the pendulum to a position where its vertical deviation is proportional to shipspeed along its sensitive axis. The signal voltages from the run pendulums due to this deviation are then cancelled by a bucking voltage that is equal and opposite to the signal voltage. However, if the azimuth gimbal tilts, the resulting signal will not be canceled by the bucking voltage and there will be an output. This is true even during ship acclerations.

We will assume that the azimuth gimbal is vertical when the ship changes speed. A voltage that varies linearly with speed is applied to terminals A and C (fig. 10-26). This voltage upsets the balance in the bridge circuit. Since the two sections of the pickoff winding are wound in opposite directions while the autotransformer windings are wound in the same direction, the magnetic fields about the pickoff windings will change. With the polarities shown in the figure, the magnetic fields around winding d are additive while those around winding e are subtractive. The stronger magnetic field around winding d will attract the pendulum bob and it will move in that direction.

If the excitation voltage and the speed voltage are out of phase, with point C negative and point B positive, the magnetic fields around winding e are additive and those around winding d are subtractive. The pendulum bob would be attracted towards winding e. In either case, the pendulum bob is off center, the bridge circuit is out of balance, and an output voltage is developed across the load resistor. But the azimuth gimbal is vertical and the output should be zero. To cancel the output, a voltage proportional to ship speed is applied to the bucking resistor. This voltage is scaled so that it is equal and opposite to the voltage on the load resistor. Consequently, although the pendulum bob is off center, there is no output from the bridge.

The speed voltage input to the run pendulum must be proportional to ship speed along its sensitive axes. The run pendulum's sensitive axes are along the N/S and E/W axes of the earth. However, shipspeed is measured along the fore-and-aft axis of own ship. Therefore, ship speed is resolved into its component parts along the N/S and E/W axes by a coordinate resolver. In this manner, ship course changes as well as speed changes are compensated for.

LATITUDE CORRECTION

It has been shown how the rotation of the earth from west to east causes the gyro to precess westward away from the local vertical. This is called apparent rotation of the gyro. To prevent apparent rotation, a torque is applied to the gyro to cause an easterly precession. The precession rate depends on the latitude and is maximum at the equator.

The latitude correction voltage is introduced into the signal circuit from the N/S run pendulum (fig. 10-27). The amount of voltage is determined by the setting of the latitude correction potentiometer. The potentiometer dial is scaled in degrees of latitude and is set to ship's latitude position. The latitude voltage causes the pitch and roll servos to drive to null the signal. If the azimuth gimbal is vertical and the gyro magnet is in the center of the pickup coils, the voltage will offset the gyro spin axis from the center of the pickup coils. The servos drive to eliminate the offset. Since the gyro is rigid, this results in the gyro's torsion wires being twisted. The wire twist will couple a torque to the N/S axis of the gyro and cause a steady and constant precession of the gyro eastward.

BIAS CORRECTION

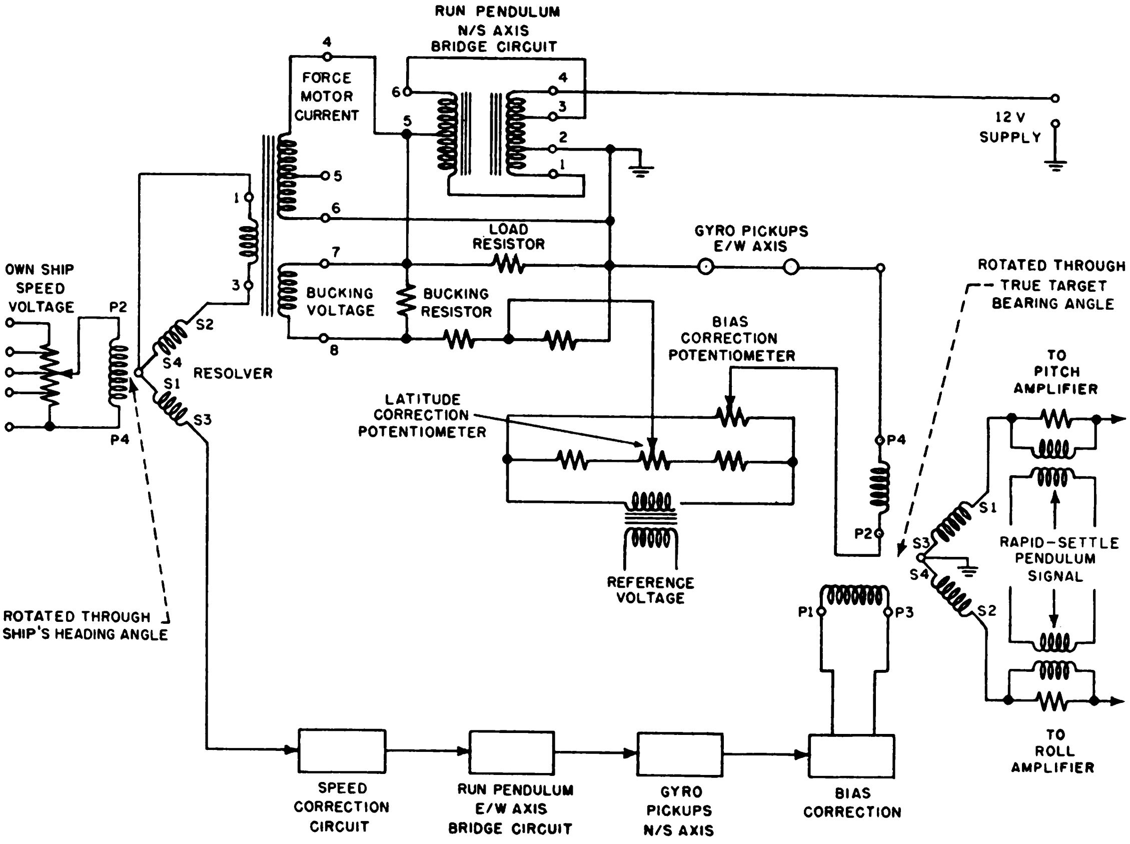
The slight physical unbalances remaining in the gyro and gimbal systems will cause what we call mechanical drift. This will cause the gryo spin axis to take an offset with respect to the pickup coils. In other words, the unbalance will cause the gyro to precess and the flotation tank to follow. The pendulum outputs will increase and try to precess the gyro back to the vertical. At some point the wire twist caused by the pendulum outputs will counteract the precession caused by the physical unbalance of the gyro system. At this point the precession will stop and the gyro spin axis will be offset from the pickup coils and the true vertical.

To reduce the offset, a bias voltage is inserted into the signal circuit (fig. 10-27). The bias is set so that it will cancel the voltages caused by the offset between the two axes (gyro spin axis and flotation tank reference line). The pendulums can then return the spin axis to the vertical. The bias voltages are introduced by two potentiometers, one in each signal circuit. The dials of the bias potentiometers are calibrated so that one division is equal to approximately three minutes of movement of the offset.

SPERRY MK 19 MOD 3 GYROCOMPASS

The Mk 19 Mod 3 gyrocompass is a navigational and fire control instrument with desig features based on unusual requirements. T compass is designed to operate in latitudes up 80° with an accuracy in heading of 0.1 degree In addition it accurately measures and transmit angles of roll and pitch. This feature distinguishe the Mk 19 Mod 3 from all other shipboard gyro compasses in use at the present time.

The Mk 19 Mod 3 gyrocompass norma acts as the primary source of roll and pi signals for Surface Missile System fire con systems. In this regard, the Mk 16 stable elem would be a secondary source for those sh so equipped. The principles of operation of t Mk 19 Mod 3 gyrocompass are basically the sa as those of the Mk 16 stable element. A FTM you will not be directly concerned with operation of the Mk 19 gyrocompass; this i responsibility of the IC Electrician. You m however, find it to your advantage to discuss t



166.34

Figure 10-27.— Pitch and roll signal circuits, simplified schematic diagram.

eration with the appropriate people aboard ur ship.

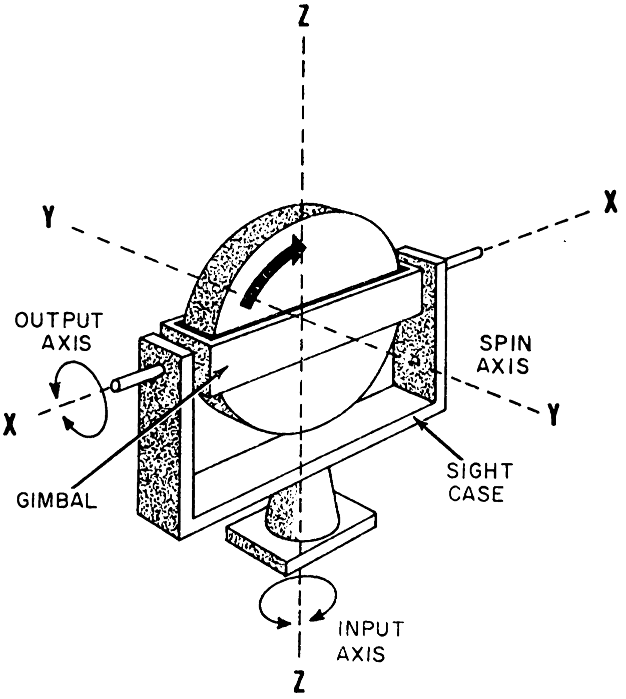
SINGLE-DEGREE-OF-FREEDOM GYROS

When we covered the degrees-of-freedom und in gyros we briefly discussed one use of single-degree-of-freedom gyro. This type of ro is used extensively in fire control equip- nt as both a computing device and a stabiliz- device. To see how it performs these functions s first look at its construction.

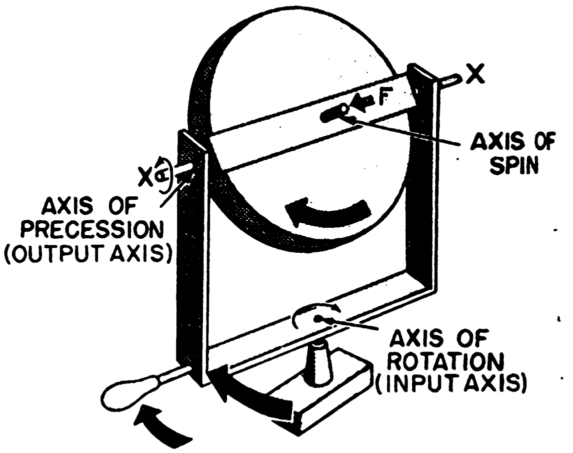
A gyro wheel is mounted in a gimbal and ns in the y-y axis, (fig. 10-28). When the wheel spinning it has rigidity in the y-y spin axis d will resist an attempt to change its plane of ation. The gimbal is supported in the two ns of the mounting frame, and can pivot about X-X output axis. The X-X axis is the only one in which the gyro can precess. In all other directions there is a fixed mechanical coupling between the gyro and its mounting. The mounting frame can be rotated about the Z-Z axis.

An angular motion about the Z-Z input axis will tend to change the gyro's plane of rotation. Therefore, if you rotate the gyro mounting about the Z-Z axis, the gyro will precess as shown in figure 10-29. Offhand, the gyro does not appear to be obeying the laws of precession. But stop to consider this: rotating the gyro case is the same as applying a force on the spin axis. Hence the direction of precession shown is correct. You can check it with the right-hand rule. A study of the figure will show that the gyro is sensitive only to angular motion about the Z-Z axis.

It is important to remember that the rate of precession is directly proportional to the precessional force, and inversely proportional to the resistance of the gyro to that force.



12.152.1
Figure 10-28.—Single degree-of-freedom gyro.



12.152.2
Figure 10-29.—Gyro precession.

Since the rate of precession is proportional to the applied force, you can increase the rate of precession by increasing the speed with which you rotate the gyro mounting. In other words, gyro precession is a result of an angular velocity about the input axis. The amount of gyro precession is determined by the strength of the precessional force, the time the force is acting, and the gyro's resistance to the force.

Initially, the gyro establishes a reference plane aligned with the center of the support arms. The gyro's displacement from the reference plane is equal to the product of the angular velocity (force) and the time the force is acting on the gyro. Mathematically a displacement is equal to the product of velocity and time. Since a single-degree-of-freedom gyro can detect and measure an angular rate of change of position of an object, it is capable of mechanically solving this type of problem.

Now let's look at some of the applications of single-degree-of-freedom gyros in fire control equipment. In fire control we are primarily concerned with the angular rate of change of a target's position. The director/radar tracks a target, measuring the target's position and changes in its position. Gyros are used to measure the angular rate of the line of sight, and hence of the target. Tracking errors are introduced into the gyro system as a rate erro or as a displacement error. The type of erro is determined by the tracking method. In som cases, where the gyro has a rate input the fire control computer solves for the tracking rate. Th computed rate is compared with the rate movement of the director as measured by the gyr

A displacement error to the gyro normall originates in the radar tracking system. Th displacement error is equal to the linear distanc between the target's present position and th line of sight. The displacement error to the gyr varies the angular rate of the director. But befor we get ahead of ourselves, in the theoretical sid of the discussion, let's go to some examples actual applications, and leave the mathematic theory to a later course. We will start with a rat of-turn, or rate gyro.

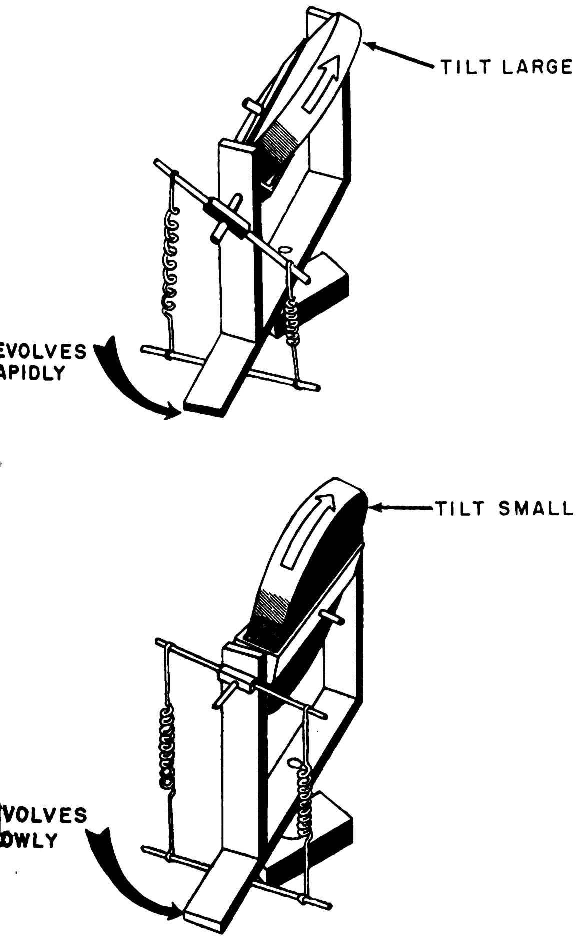
RATE GYROS

Rate gyros found in fire control equipme may be called by different names, dependin what OP or other reference you are read Nevertheless, no matter what name is appli to a gyro which measures rate of change it c be called a rate gyro.

Like the free and vertical gyro, the ra instrument contains a mechanical system co sisting of the spinning rotor and associated gi bal system. It differs in that it has one gimba so that one degree of freedom is obtained. Fur-ther, the rotor is restrained by some means, usually a spring, when it is precessed.

Rate-Of-Turn Gyro

A rate-of-turn gyro is installed to take dvantage of the property of precession. This recession is carefully measured in terms of earing and elevation target tracking rates. hese rates, after certain modifications, are used o compute the prediction quantities of our issile fire control problem. There is nothing ke a good concrete example to explain why yros are used to calculate the angular rates of igh speed targets.



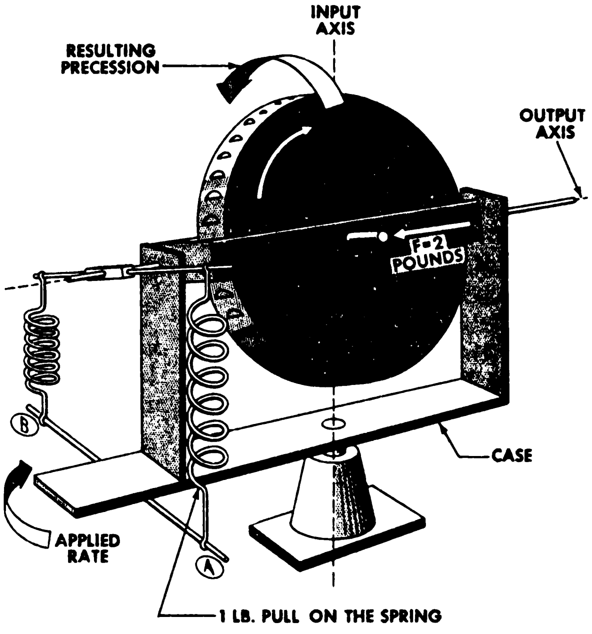
12.152.3
gure 10-30.—Precession is proportional to the rate-of-turn.

Consider the case of a high speed jet fighter sweeping by your ship at a 1000-yard range. His bearing rate would be so fast that a mechanical computer would not have time to arrive at a solution.

But the fact remains that these targets are dangerous and have to be knocked down. This means that some type of computing mechanism must be used; a type which is still faster than the ones using the mechanical components you have studied in previous chapters. And the GYRO is the answer.

You know that a force applied at F will cause the gyro to precess at right angles to the force, (fig. 10-29). Likewise, attempting to turn the gyro case will cause the same result. The gyro will precess as shown by the arrows, around the x-x axis.

Since the rate of precession is proportional to the applied force, you can increase the rate of precession by increasing the speed with which you are moving the gyro case (fig. 10-30). In other words, you have a RATE-OF-TURN GYRO. The FASTER you turn the gyro case, the MORE the GYRO will PRECESS, for the amount of precession is proportional to the rate of turn.



12.153
Figure 10-31.—Precession of a spring restrained rate-of-turn (rate) gyro.

Figure 10-31 illustrates a method of restraining (controlling) the precession of a gyro to permit the calculation of a target rate. A pair of SPRINGS has been attached to the crossarm on the x-x shaft. These springs serve to restrain the FREE precession of the gyro. The gyro is harnessed to produce some useful work.

As a gyro precesses, it exerts a force which is proportional to the momentum of the spinning wheel and the applied force.

For example, suppose you rotate the gyro case at a speed which is proportional to applying a horizontal force of 2 pounds at F. Obviously, the gyro will precess; and as it does, it will cause the crossarm to pull up on spring A with a CERTAIN FORCE—say 1 pound. (This would vary with the length of the crossarm.)

If you CONTINUE to turn the gyro case at this rate, the precession of the gyro will continually exert a pull on the spring. More precisely, the gyro will precess until the 1-pound pull of the crossarm is exactly counterbalanced by the tension of the spring.

The gyro will continually try to precess farther, but since its pull is balanced by the tension of the spring, it will remain in a fixed position as shown in figure 10-31. That is, it will REMAIN in the PRECESSED POSITION as long as you CONTINUE TO ROTATE THE CASE AT THE SAME CONSTANT SPEED.

When you stop moving the gyro case, it is equivalent to removing the force at F, and the gyro stops precessing. The spring is still exerting a pull, however, so it pulls the crossarm back to the horizontal.

Suppose you rotated the case twice as fast as before. That would be equal to a 4-pound force at F and a resulting 2-pound pull by the cross-arm on spring A. So the gyro would precess twice as far, before the tension on the restraining spring equalled the pull of the crossarm.

Boiling it down the faster you rotate the gyro case the further the gyro will precess before the pulls of the crossarm and spring are equal, and the gyro comes to rest.

FLOATED GYRO UNIT

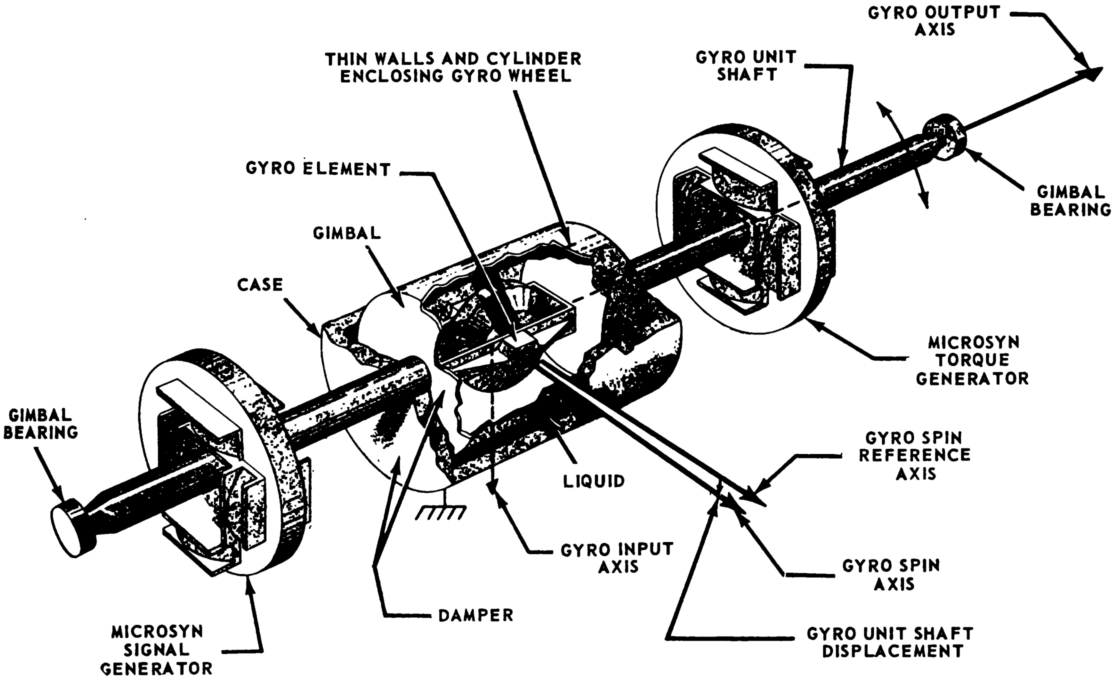
Another type of gyro widely used in fire control equipment is the floated gyro unit. This unit, also called the draper gyro and hermetically sealed integrating gyro (HIG), to list a few of its more common names, is a viscous damped, single-degree-of-freedom gyro with a torque generator and a signal generator mounted on its output shaft. Figure 10-32 shows a cutaway view of the unit. The principal components of the gyro are the gyro rotor, gimbal, signal generator, torque generator, and the viscous damping fluid. The gyro rotor and stator are in a sealed cylinder filled with a gas, usually helium. The gas serves to transfer heat generated by the gyro stator windings to the surface of the cylinder. The closed metal cylinder acts as the inner gimbal and is mounted on precision bearings. The space between the gimbal and case is filled with a viscous damping fluid of high specific gravity. Because of the high specific gravity of the fluid it serves to float the inner gimbal and its shaft. This reduces the gimbal bearing friction. In this way mechanical drift due to friction is greatly reduced.

The "pick off" is a signal generator whose rotor is attached to one end of the inner gimbal shaft. (The term "pick off" is the name usually used for that part of a gyroscopic unit whose function is to change the output of the device into a usable signal.) The electrical output of the signal generator is proportional to the angular displacement between the inner gimbal and the case. The torque generator, the rotor of which is attached to the other end of the inner gimbal shaft, provides a means of applying command signals to the gyro to cause it to precess

Automatic Tracking Systems

A typical fire control application of a flo
gyro unit is in the automatic radar track
(angle servo) circuits of fire control directo
or radar sets. Before discussing the action
the floated gyro unit, it is necessary to consi
first the overall operation of the entire track
system. We will divide it into convenient gro
of units and indicate the general function of e
unit, so that their operation may be underst
in relation to the operation of the system a
whole. The complete system is used for tra
ing tragets automatically, and for stabilizing
line of sight in the presence of ship motion
may be considered as consisting of six ma
units: the radar receiver, the angle error c
cuits, the rate gyro unit, power drive servo c
cuits, power motor, and the radar ante

Operating together, these groups of eq
ments function as a large servomechanis
position the radar antenna. Conception of
radar automatic tracking loop as a servome
anism can be represented by means of a ge
alized block diagram as in figure 10-33.
figure refers to no particular system. It i
cates the basic types of components, and ante



12.154

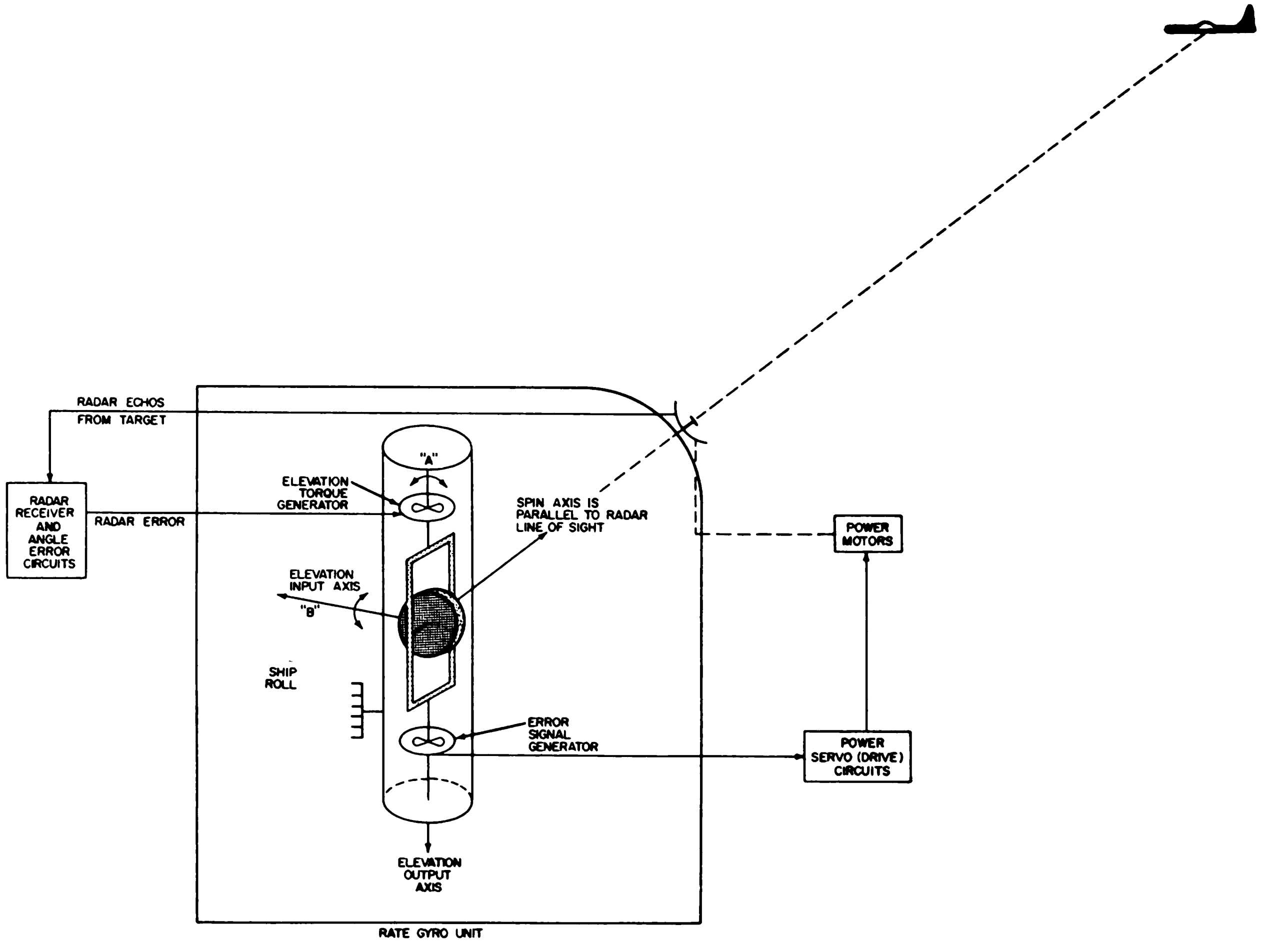
Figure 10-32.—Floated gyro unit.

ontrol methods usually employed in the eleva-ion tracking circuits of missile fire control ystems.

The following describes what takes place in e system in case of an elevation radar error ignal and ship's motion. Operation is essen-ally the same for traverse. The radar receives rget echoes from the antenna and converts em into radar error signals. These signals dicate how far and in what direction the radar im is off target. They are applied to the gyro it torque generator to cause the gyro to pre-ss so that its spin axis swings in the direction which the radar beam should move to follow e target. Appropriate error signals are pro-ced by the signal generator and sent to the tenna power drives to cause the radar beam align itself with the gyro spin axis. In this nner the radar beam continuously tracks a rget. This method of control illustrates how e principle of gyroscopic precession is used. e fundamental principle of rigidity of a gyro n also be shown.

Assume for the moment that the radar an-na is not tracking a target. This produces no dar error signal. The ship starts to roll and pitch. A torque is produced about the input axis of the gyro in the gyro unit, precessing the gyro and turning the output shaft. Error signals are generated by the signal generators proportional to the rate of change of ship motion. These signals are amplified and sent to the power drives to position the antenna. Movement of the antenna causes the gyros to precess to their original position. This action has the effect of making the radar line of sight remain fixed in space while the ship rolls and pitches beneath it.

Now that you have an overall picture of how the elevation automatic radar tracking circuit works, let's take a closer look at the rate gyro unit. Figure 10-33 shows a simplified block diagram of it. The elevation radar error signal is applied to the torque generator, producing a torque "A" about the gyro output axis. At the same time, any torque caused by ship roll or pitch that may be present about the input axis will cause the gyro to precess. This torque is marked "B" in the figure, and it produces another torque about the output axis. Torques "A" and "B" are algebraically added about the output axis. The resultant torque or twisting effect is opposed by the viscous fluid. Since the viscous


RADAR ECHOS
FROM TARGET
RADAR RECEIVER AND ANGLE ERROR CIRCUITS
RADAR ERROR
"A"
ELEVATION TORQUE GENERATOR
SPIN AXIS IS PARALLEL TO RADAR LINE OF SIGHT
POWER MOTORS
ELEVATION INPUT AXIS
"B"
SHIP ROLL
ERROR SIGNAL GENERATOR
POWER SERVO (DRIVE) CIRCUITS
ELEVATION OUTPUT AXIS
RATE GYRO UNIT

12.155.

Figure 10-33.—Simplified block diagram of an automatic tracking system.

fluid has integrating properties, the signal generator rotor will be turned through an angle which is the integral of the resultant torque. In other words, the output of the signal generator depends upon the total torque causing precession and the duration of precession. The output of the signal generator drives the elevation power servo to move the antenna. Movement of the antenna cancels the radar error signal, and removes the signal to the torque generator. As the antenna moves in elevation, the elevation gyro is precessed in a direction to zero the output of the signal generator.

A second method of using this type gyro in a director drive is with a rate input to the torque generator. In figure 10-34 the fire control computer solves for the angular tracking rate. The computed rate is transmitted to the directo drive to control its angular velocity. The angula motion of the director will cause gyro precession. The gyro signal generator's output is pr portional to the angular velocity of the directo The gyro velocity signal is added to the computed velocity signal in the summing networ The sum of the two is the input signal to t power drive.

At the same time the gyro signal is fed ba to the gyro torque motor. The motor will app a torque to the gyro to tilt it back toward neutral reference plane. Therefore the gyro delicately balanced between the precessio force "B" caused by the director rotation a the feedback torque "A", which is a measure the present angular velocity of the director. A

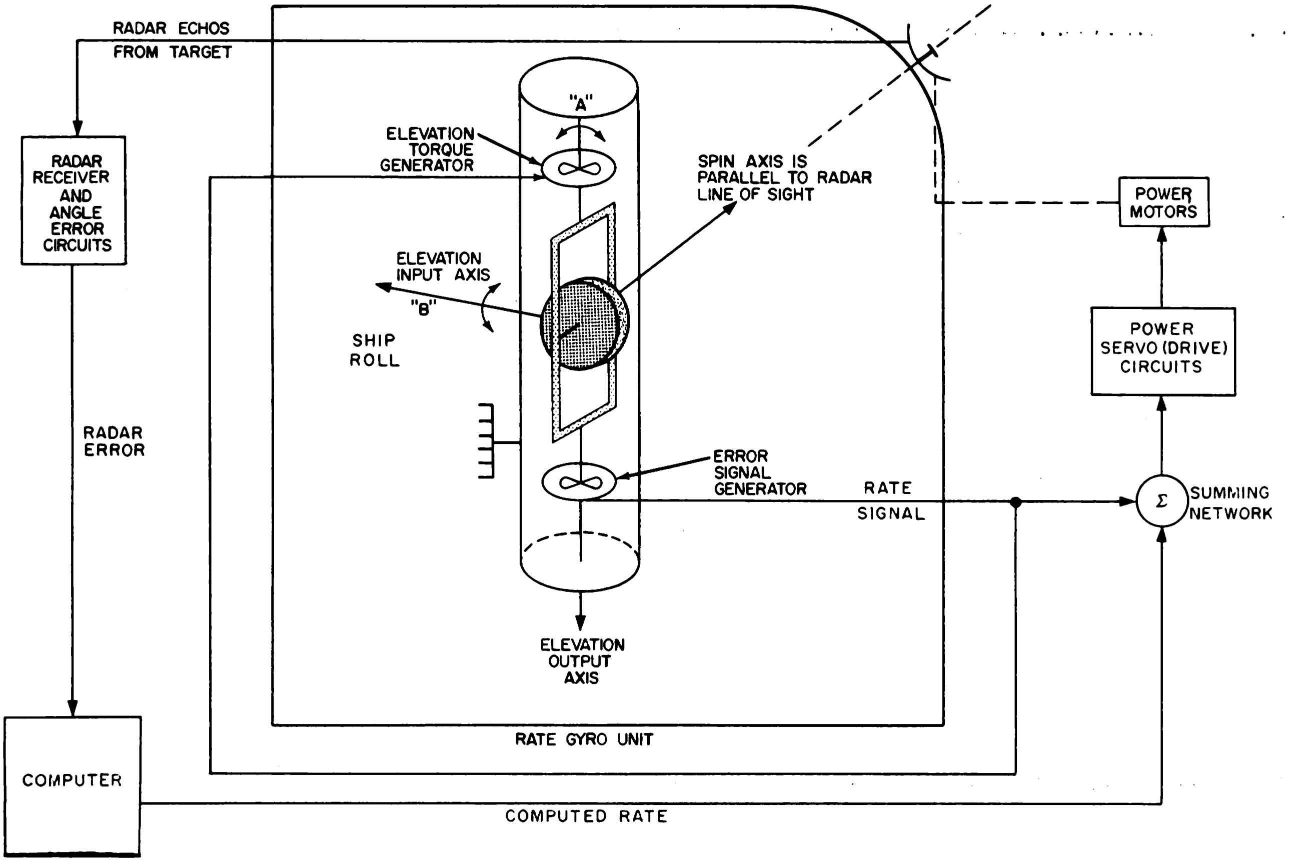


Figure 10-34.—Simplified block diagram of an automatic tracking system with rate signals.

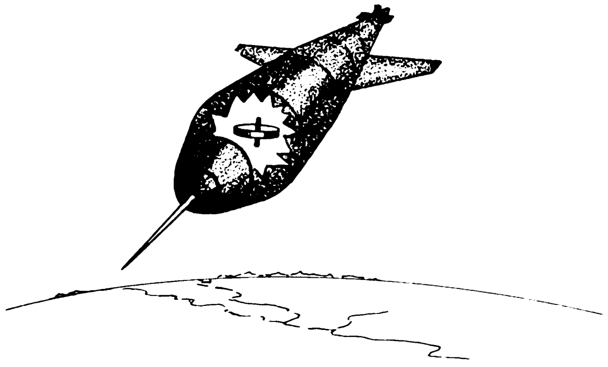
change in the director's angular velocity will change torque "B", which will distrub the gyro balance and cause it to precess. The output of the gyro signal generator will therefore be proportional to the rate of change of velocity, or an acceleration signal.

GYROS USED IN GUIDED MISSILES

FREE GYROS

To illustrate how free gyros are used in detecting missile attitude, let us first refer to figure 10-35. Suppose that the design attitude of the missile is horizontal as shown in the figure. The gyro within the missile has its spin axis in the vertical plane, and is mounted in gimbals in such a manner that a deviation in the horizontal attitude of the missile would not physically affect the gyro. In other words, the missile body can roll around the gyro and the gyro will still maintain its same position in space. Figure 10-36 shows this occurrence. Note that the missile has rolled approximately 30°, but the gyro has remained stable in space. If we could measure the angle between the rotor and a point on the missile body we would know exactly how far the missile deviated from the horizontal attitude. Having determined this, the control surfaces could then be positioned to return the missile to the horizontal.

Actually, a minimum of two free gyros is required to keep track of pitch, roll, and yaw. The vertical gyro just described can also be used to detect missile pitch as shown in figure 10-37. To detect yaw, a second gyro is used with its spin axis in the horizontal plane and its



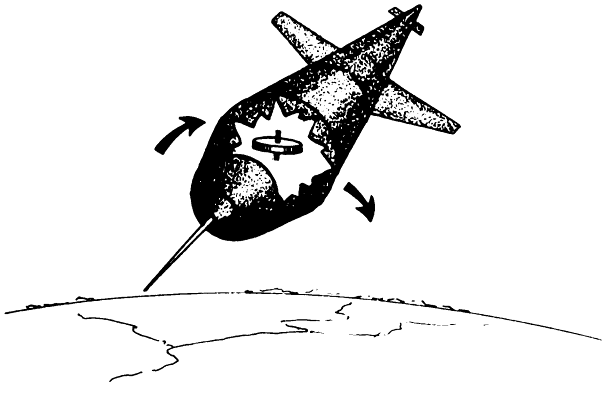
33.67

Figure 10-35.—Missile horizontal-gyro stable in space.

rotor in the vertical plane. Yaw will then be detected as shown in figure 10-38.

RATE GYROS

The free gyros just described provide a means of measuring the AMOUNT of roll, pitch, and yaw. The free gyros therefore can be used to develop signals, which are proportional to the amount of roll, pitch, and yaw. Due to the momentum of a missile in responding to free gyro signals, large overcorrections would result unless there were some means of determining how fast the angular movement is occurring. For example, suppose that a correction signal is generated which is proportional to an error of 10° to the left of the proper heading. The control surfaces are automatically positioned to bring the missile to the right. The missile responds by coming right. But because of its momentum it will pass the correct heading and introduce an error to the right. To provide correction signals that take momentum of the missile into account, rate gyros are used. These gyros continuously determine angular accelerations about the missile axes. By combining free gyro signals with rate signals from the rate gyros, the tendency to overcorrect is minimized and a better degree of stability is obtained. The rate gyro actually provides a refinement or damping effect to the correcting process. Without rate gyros, a missile would overcorrect constantly.



33.68

Figure 10-36.—Missile rolls-gyro remains stable.

The basic difference between the free gyro and the rate gyro is in the way they are mounted. Figure 10-39 shows a simplified view of a roll rate gyro. Notice that the rotor is mounted in single gimbals rather than the two sets of gimbals which support the free gyro. This arrangement restricts the freedom of the gyro rotor. When the missile rolls, the gyro mounting turns about the roll axis (arrow A) carrying the gyro rotor with it. This causes a force of precession at a right angle to the roll axis, which causes the rotor to turn about the pitch axis (arrow B).

Restraining springs may be attached to the gimbals as shown. The force on the springs woul then be proportional to angular acceleration abou the roll axis.

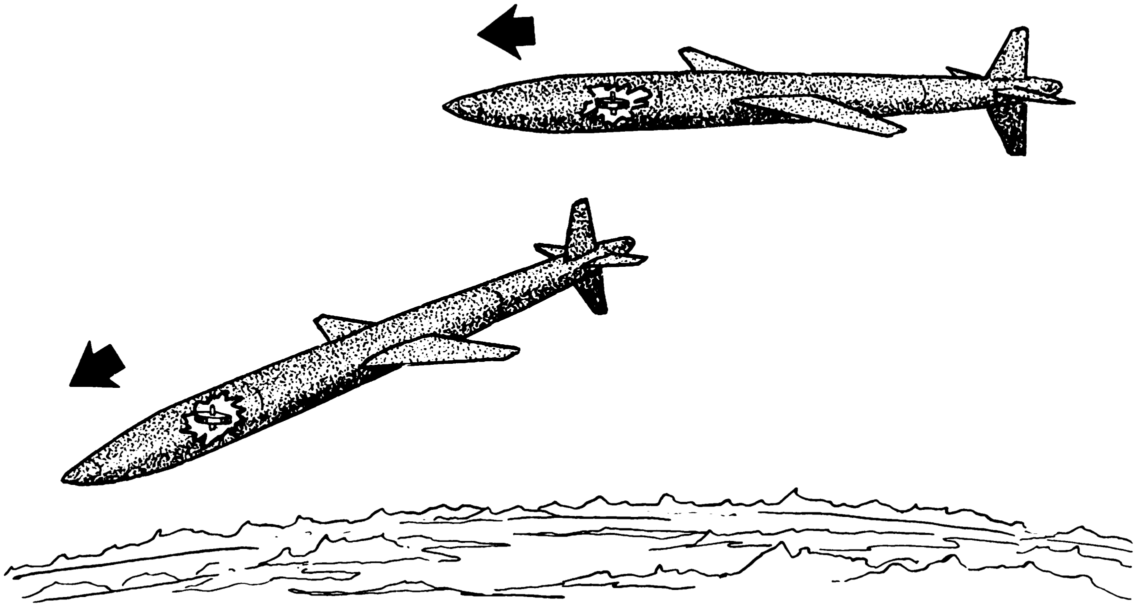
Three rate gyros are normally installed in missile to measure the accelerations about the three mutually perpendicular missile axes.

SENSORS

Earlier in this chapter we discussed th sensing element of the basic stable elemen Remember the figure-eight coils and the electro magnet. Two other sensors worthy of mentio at this time are the crossed-E transformer a the microsyn.

E-TRANSFORMERS

The simplest form of the E-transformer i shown in figure 10-40. An alternating volta is applied to the primary coil on the cent



33.69

Figure 10-37.—Missile pitches-gyro remains stable.

le of the laminated E-shaped core. Two sec-
dary coils (1 and 3 in the figure) are wound in
ries opposition on the outer poles of the struc-
re. The magnetic coupling between the pri-
ry (coil 2) and the two secondaries varies
th the position of the armature. The arma-
re can be displaced laterally in either direc-
n in the magnetic circuit. This changes the
uctance between either pole and the armature.

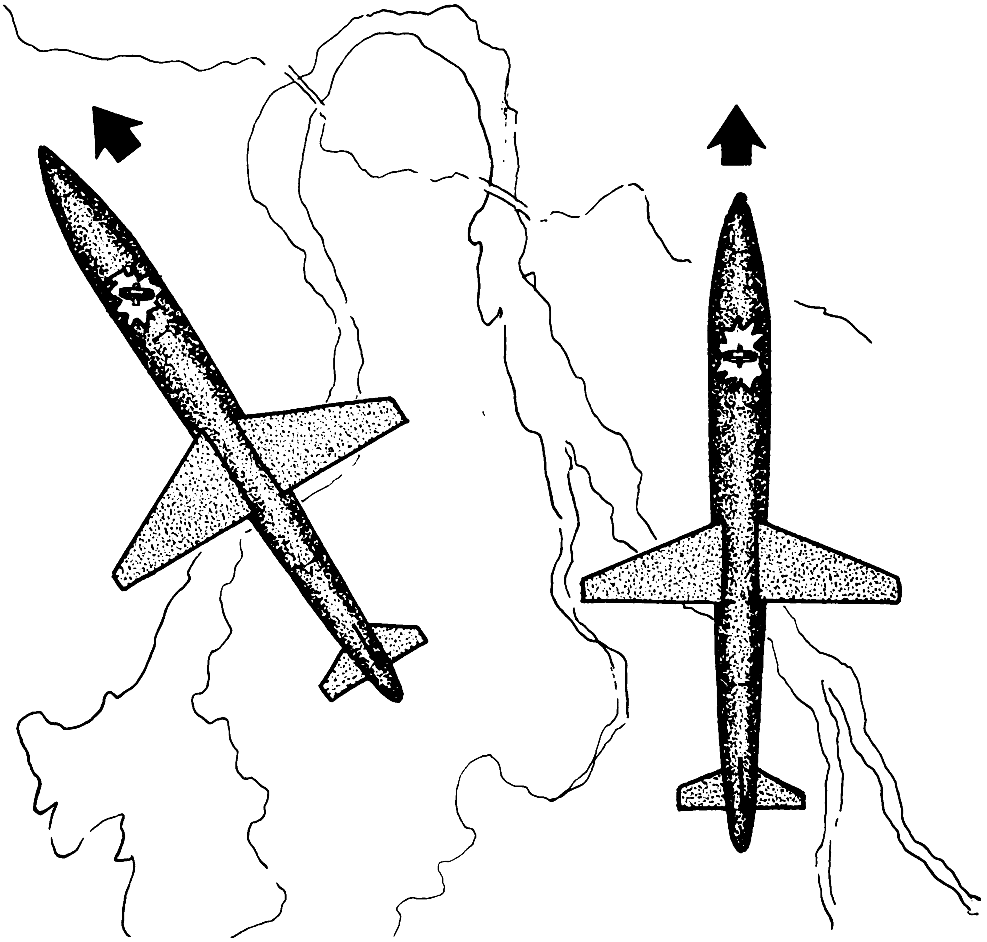
When the armature is located in the center
the structure, as shown in the figure, equal
tages are induced in the secondary coils, and
difference between them is zero. Thus, the
tage at the output terminals is also zero.

But if the armature is moved, say, to the
it, as shown in figure 10-41, the voltage in-
ed in coil 1 increases, while the voltage
iced in coil 3 decreases. The two voltages
then unequal, so that the difference is no
er zero, and a net voltage results at the
ut terminals. A sense of direction is pro-
d since the output voltage changes phase as
armature passes through the null (center
tion). The output voltage phase will be either
hase with the primary voltage or 180° out of
e. The amplitude of the output voltage is
proportional to the amount the armature moves back and forth from the center position.

Crossed-E Transformer

E-type transformers are used in fire control equipment to measure angular movement; therefore, the basic E-transformer just described must be altered slightly to perform this function. If you place two E-transformers at right angles to each other and replace the bar armature with a dome-shaped one, you have the basic configuration of what is known as the crossed-E transformer, or pickoff. In most applications the dome-shaped armature is attached to a gyro, and the core assembly is fixed to a gimbal which is the servo load.

The crossed-E transformer assembly consists of five legs (poles). Each leg is encased by a coil. The coil around the center leg is the primary, which is excited by an alternating voltage. The remaining four coils are the secondaries. Figure 10-42A shows a cross-sectional view of the crossed-E transformer and the flux paths through the armature. Part B of figure 10-42



33.70

Figure 10-38.—Missile yaws-gyro remains stable.

shows how the crossed-E transformer looks from the front. From this view you can see how it gets the name, crossed-E.

To understand the operation of the crossed-E transformer, let's see how it works in a typical director-positioning servo. Figure 10-43 shows a simplified block diagram of a train power drive.

Let us assume that the director is tracking, and that the target is moving to the right. The current (which represents tracking error) through the traverse torque motor will cause the motor to precess the gyro clockwise as indicated in figure 10-43. The gyro is positioned slightly to the left of center of the transformer. The core assembly is carefully positioned on the gyr gimbals so that the core axis is parallel t the line of sight. You can see the relationshi in figure 10-44.

When the reluctance dome, and thus the gyr spin axis, is to the left of center, more flu links the left leg with the primary coil and th voltage induced in the left secondary increases The right leg has fewer flux linkages with th center coil; therefore, the voltage induced i the right coil will be less than that in the le coil. Thus there will now be a net voltage ou of the pickoff. The phase of the output will b that of the larger voltage. It follows that if th gyro were torqued to the right, the opposite condition would exist. From this brief description you can see that the crossed-E transforme

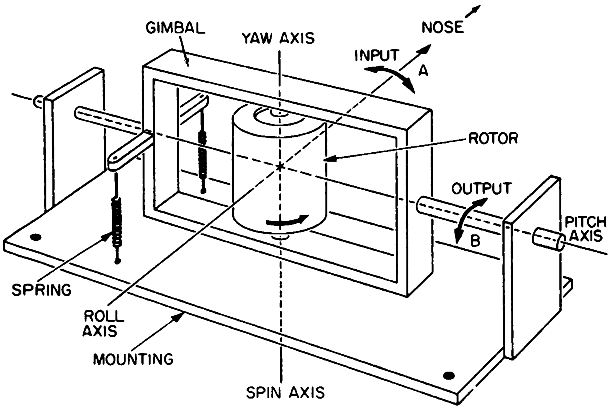


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Figure 10-39.—Roll rate gyro.

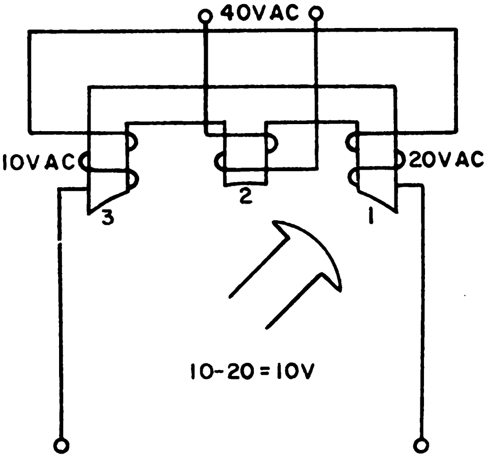

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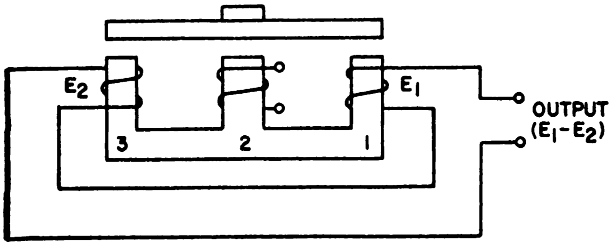
Figure 10-41.—Basic E-transformer with armature offset from center position.

works on the same fundamental principle as the basic type described earlier. The major difference between the two is in shape and the number of secondaries, and in the fact that the armature has universal movement.

The signal from the transformer ultimately drives the director until the axis of the center leg of the core assembly is in coincidence with the axis of the reluctance dome. When this occurs, the line of sight is on target and no radar tracking error exists. Note again that this servosystem, in block form, contains all the essential parts of a basic servo.

Stable Element Crossed-E Transformer

Another application of crossed-E transformers as a pickoff or error detector is in stable element servosystems. Figure 10-45 shows a simplified block diagram of a pitch servo. The roll servo is identical but is deleted for clarity.



55.19

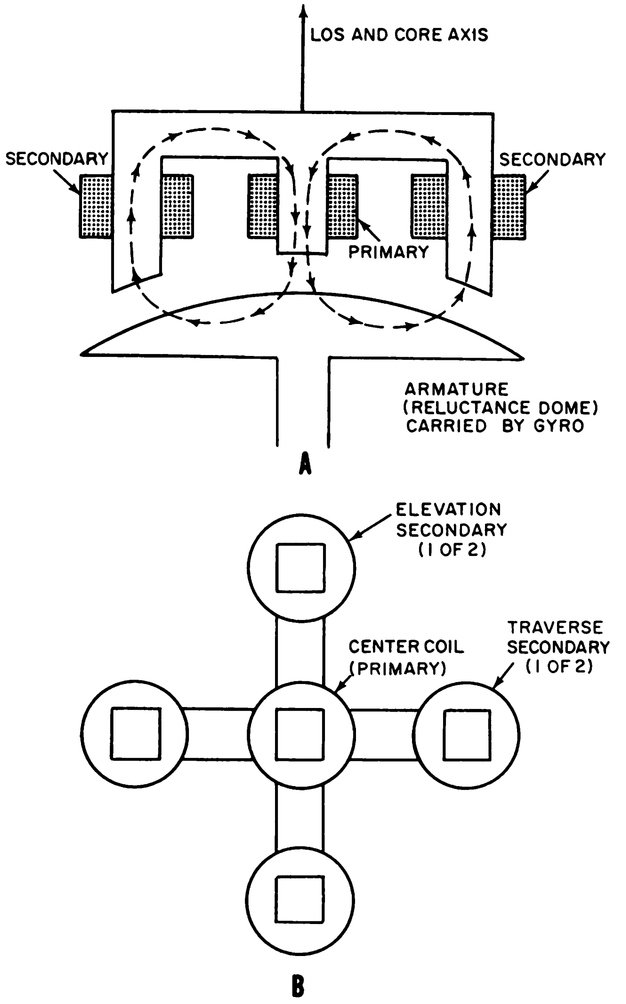
Figure 10-40.—Basic E-type transformer with armature at null (zero) position.

Roll or pitch movement, or both, of the ship displaces the pickoff core from its position directly over the gyro. The vertical axis of the gyro represents the vertical. Any slight displacement of the core, and thus of the secondary windings, causes generation of an error signal. The pitch and roll servosystems operate in response to these error signals and return the pickoff core to its original position. The amount and direction of travel of the pickoff core is transmitted in the form of synchro signals or appropriate mechanical motion to the equipment being stabilized.

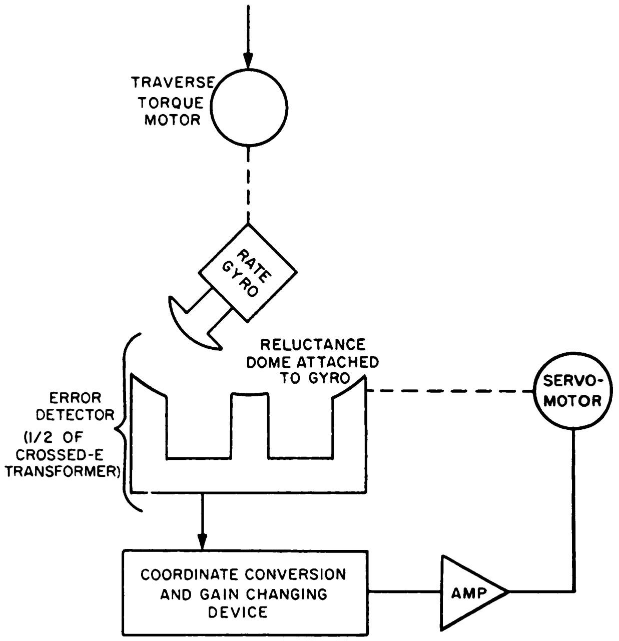
THE MICROSYN

The microsyn, shown in figure 10-46, is frequently used as a torquer or pickoff in gyro units in director and antenna-positioning servos. Microsyns are also used in gyro units that are part of inertial guidance systems. The microsyn is an error-detecting, measuring, or similar device which can be used either as a transmitter (signal generator) or a receiver (sometimes referred to as a torquer, torque motor, or torque generator.)

Either unit consists of a bobbin-shaped two-pole rotor and a four-pole stator. The four



55.21A
Figure 10-42.—Crossed-E transformer: A. Cross section; B. Front view.



55.22
Figure 10-43.—Train power drive (positioning).

poles are displaced 90° from each other. A primary coil and a secondary coil are wound on each pole. The rotor has no windings, and serves only to change the reluctance of the magnetic paths between the stator poles. The rotor is mounted on ball bearings. Because it has no winding, no electrical connections, such as brushes or sliprings, are required.

When the microsyn is used as a transmitter, its output is a voltage whose phase is determined by the direction of rotor movement. The amplitude of the output voltage is proportional to the amount the rotor is displaced. When used as a receiver, its output is a torque—hence the name torquer or torque generator. The direction of the torque is determined by the phase relationship between the two input voltages, and its magnitude is determined by the amplitude of the variable input voltage.

Microsyn Transmitter

In the transmitter or signal generator unit the four primary coils are connected in series and are excited by a 400-Hz reference voltage. Other frequencies are used, but 400 Hz is most common. The coils are wound so that the flux in pole 1 aids the flux in pole 4, and the flux in pole 2 aids the flux in pole 3. When the rotor which is attached, say, to the output shaft of a gyro, is in the zero position as shown in figure 10-46A, equal amount of rotor iron are under each of the four pole faces. In this position, the pole 1-pole 4 flux through the rotor equals the pole 2-pole 3 flux through the rotor. Equal voltages are now induced in the secondary coils. These four secondary coils are also connected in series. The voltage induced in the pole 1 secondary aids the voltage induced in the pole 3 secondary. The combined voltages in the pole 1

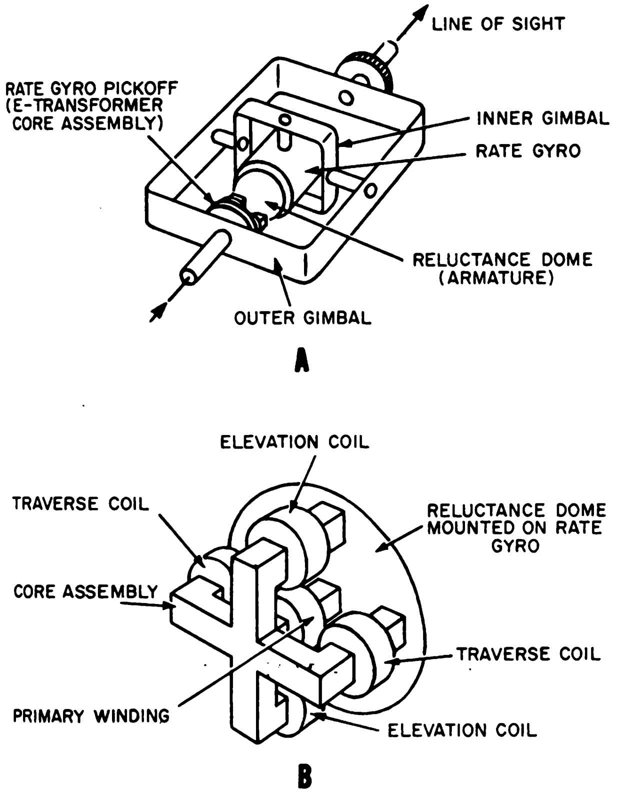


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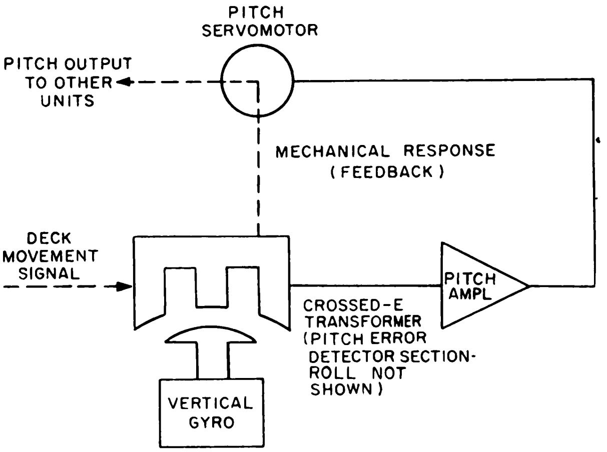
Figure 10-44.—Crossed-E transformer in director positioning servo: A. Location of components; B. Relationship between core assembly and reluctance dome.



55.24

Figure 10-45.—Simplified block diagram of a stable element pitch or roll servo.

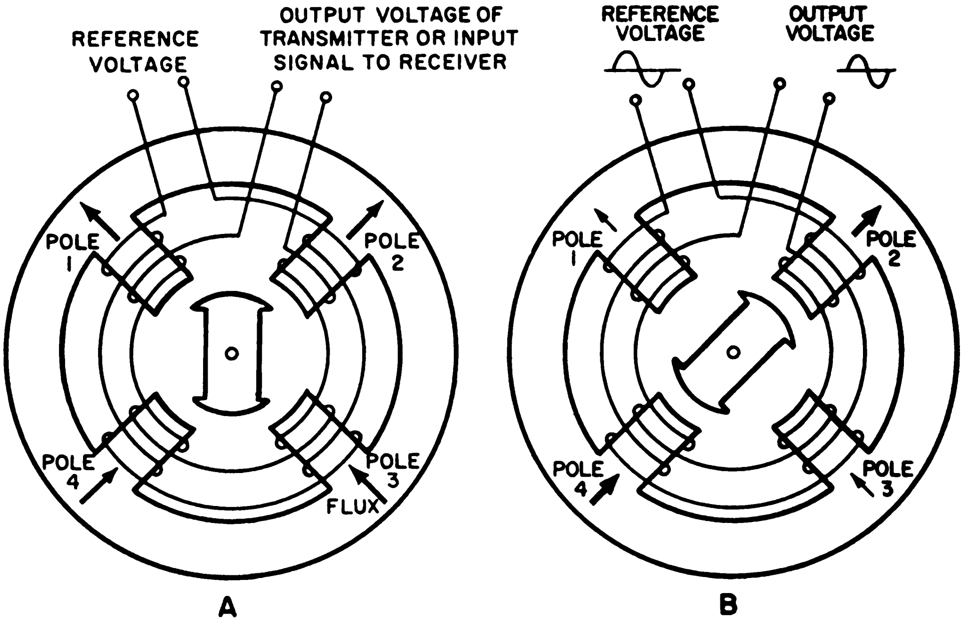
and pole 3 secondaries oppose the combined voltages of the pole 2 and pole 4 secondaries. When the rotor is at the zero position, these two pairs of combined voltages are equal, and the output of the microsyn transmitter is zero.

When the rotor of the microsyn transmitter is turned to the right (fig. 10-46B) by a mechanical input, in this case gyro precession, the amount of rotor iron under poles 2 and 4 exceeds the amount of rotor iron under poles 1 and 3. The total voltage induced in the secondary coils of poles 2 and 4 now exceeds that induced in the secondary coils of pole 1 and pole 3. Under this condition the phase of the output voltage is that of the voltage induced in the secondary cells of poles 2 and 4, and the amplitude of the output voltage is equal to the voltage induced in secondary coils 2 and 4 minus the voltage induced in secondary coils 1 and 3. If the rotor of the microsyn is turned to the left, the magnitude of the output voltage equals the voltage induced in secondary coils 1 and 3 minus the voltage induced in secondary coils 2 and 4. Thus, the microsyn transmitter has an output voltage whose phase is determined by the direction of the rotor displacement from zero and whose amplitude is determined by the amount of this displacement.

Microsyn Receiver

This unit is physically and electrically identical to the transmitter. However, the rotor is free to turn. The rotor can be attached to the input shaft of a rate gyro. When the reference voltage alone is applied to the primary, the fields produced in the four primary coils will position the rotor to zero so that equal amounts of rotor iron are under each of the poles. If a voltage in phase with the reference voltage is applied to the secondary coils, the flux produced in poles 2 and 4 by these coils aids the flux produced by the primary coils. Meanwhile the flux produced in poles 1 and 3 by the secondary coils opposes the flux produced by the primary coils. The magnetic field produced in poles 2 and 4 is stronger than that produced in poles 1 and 3. Therefore a torque, exerted on the rotor, will attempt to increase the amount of rotor iron under poles 2 and 4.

If the phase of the voltage applied to the secondary coils is reversed, the direction of the



55.26

Figure 10-46.—Microsyn torque or signal generator: A. Rotor at zero; B. Rotor displaced to right.

resultant torque will be reversed. Therefore, it can be said that the microsyn receiver produces a torque whose direction is determined by the relative phase of the reference and signal voltages, and whose magnitude is determined by the amplitude of the signal voltage.

GYRO DAMPING

In order for a gyro to function smoothly, damping of the gyro unit output shaft is essential. The damping supplies a restraining force on the gyro output proportional to the rate at which the gyro is precessing. If the precession angle is not changing, the damping mechanism has no restraining effect and does not influence the angles. Damping causes the gyro to precess slowly and approach the correct precession angle smoothly.

Damping is normally accomplished by submerging the gyro unit in a viscous liquid (fig. 10-32). As pointed out earlier, this liquid causes the gyro unit to float. Liquid contact is with the cylinder that encloses the gyro wheel. The cylinder is attached to the gyro unit shaft and turns with it. The movement of the cylinder is resisted by the liquid in which it is floating. The effect is a smoothing or damping action.

The amount of resistance that the liquid offers depends on its viscosity which is a function of its temperature. The fluid is heated electrically, and its temperature is controlled by a thermal switch.

CHAPTER 11

INTRASHIP DATA TRANSMISSION

INTRODUCTION

The need for a lot of information to solve the missile fire control problem has already been established. This information must be sent back and forth between equipment located at a distance from each other. For example, a missile fire control computer requires inputs from numerous pieces of equipment that are located at distances from a few feet to possibly several hundred feet. It is essential that the fire control technician be knowledgeable concerning shipboard data transmission techniques.

This chapter will provide you with essential information concerning shipboard data transmission systems. Your studies will provide you with an understanding of data transfer in both analog and digital transmission systems. Along with this, you will develop the knowledge required to properly understand alignment procedures employed with data transmission devices. Finally, you will become more familiar with the techniques employed in converting analog/digital data from one form to the other.

CLASSIFICATION OF DATA TRANSMISSION SYSTEMS

Fire control data can be classified within the two broad categories of digital data and analog data. Further classification can take place according to the manner in which the data are transmitted or developed.

In chapter 7, you learned that digital data (bits) can be transmitted in serial or parallel form. You are also aware that digital and analog data can be converted from one form to the other. Later this chapter will further discuss this along with the actual transmission of digital data (bits) from one quipment to another.

Many fire control quantities have quantitative or numerical values that must be transmitted in order to describe the quantity. These quantities, which are for the most part analog, are transmitted in a form which is convenient for transmission. A quantity can be defined in many types of measures. Hence we can transmit quantities such as range, elevation, or traverse as voltages in an electrical circuit, as mechanical motions in a mechanical system, or as pressures in a hydraulic system. In this chapter we will concern ourselves primarily with electrical transmissions.

BASIC TRANSMISSION SYSTEM

All intraship transmission systems consist basically of a signal producing device (transmitter), a transmission medium (conductor), and a receiver (load) (fig. 11-1). Synchros, resolvers, microsyns, crossed-E transformers, and potentiometers are examples of devices that can be employed as transmitters. You are already familiar with the operating principles of these devices. Synchros and resolvers, however, lend themselves to lengthier discussions due to their extensive application. First, however, let's look at a simplified switch controlled transmission system.

SWITCH CONTROLLED TRANSMISSION SYSTEM

Information can be transmitted by the presence or absence of a voltage. This is probably the simplest of data transmission systems. These systems, however, are limited in capability to

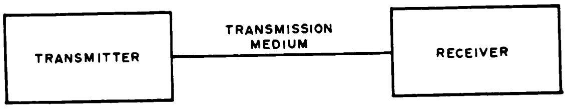


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Figure 11-1.—Basic data transmission system.

the less complicated signals. Circuits similar to those in figure 11-2 are used to transmit an order or to indicate a condition. When a switch in the circuit is closed, the indicating device is energized.

The circuits showns are simplified. Frequently other switches or relay contacts are in series with the master switch. The other switches or contacts establish necessary conditions before the circuit is complete. For example, in order to energize the "Ready to Fire" bus of figure 11-2C, the firing safety switch must be in the FIRE position and the following conditions must be met:

1. The launcher is loaded and synchronized with fire control computer orders.
2. The missile has acquired minimum warmup.
3. The blast doors are closed.
4. The missile gyros are caged.
5. The launcher is not in a firing cutout zone.
6. The position of the SALVO SELECT switch corresponds to the desired rail loaded condition.

As the aforementioned conditions are fulfilled, appropriate relay switching takes place which will complete the energizing path for the READY TO FIRE relay.

The READY TO FIRE bus will be used to energize a relay which will close a set of contacts in the missile firing circuit. At the same time, a READY TO FIRE indication will be received at the missile firing panel indicating that conditions have been fulfilled to ensure a safe missile firing.

Control circuits similar to the one just described are quite common in today's fire control systems. In all cases, the circuits provide yes/no indications of system status or condition. For details concerning the relay control circuits of your system, refer to your equipment OPs.

SYNCHRO SYSTEMS

Fire control position information is transmitted electrically between distant stations by synchro systems. All SMS fire control systems make extensive use of this form of data transmission, therefore, knowledge in this area is mandatory. In chapter 5, it was suggested that you review synchros as presented in Basic Electricity, NavPers 10086-B. If you did not, it is

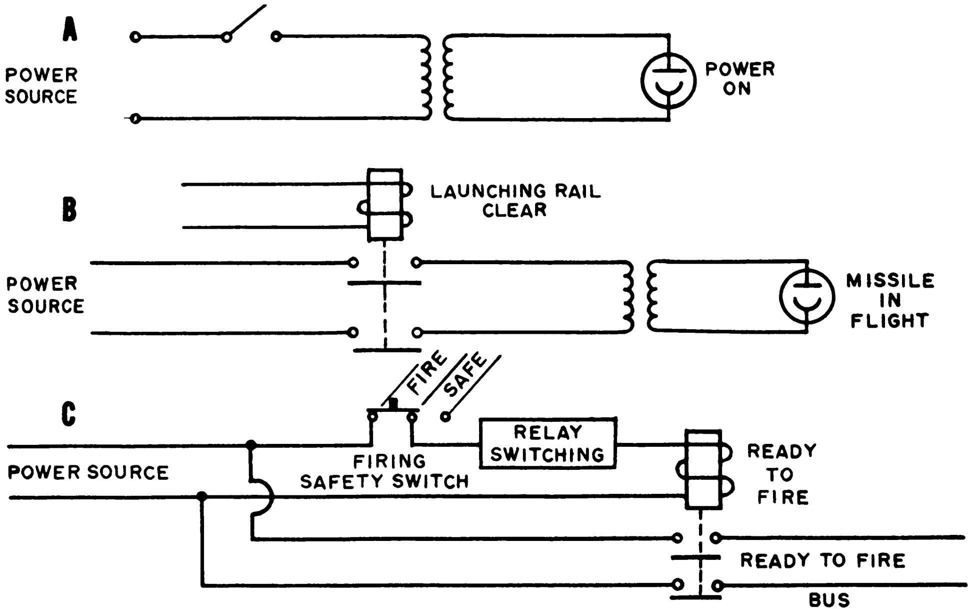

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Figure 11-2.—Switch controlled transmission systems.

advisable that you do so now before continuing with this chapter.

TYPES OF SYNCHROS

Before we cover the types of synchros, we will briefly summarize their common features and characteristics. Synchros are basically transformers. Various types have been developed to serve several different purposes. They are usually position-sensing devices which have the following things in common:

1. They operate on a transformer principle.

2. They have a "Y" connected stator. (Three windings 120° apart, each with a common connection. These three windings correspond to one of the windings of a transformer.)

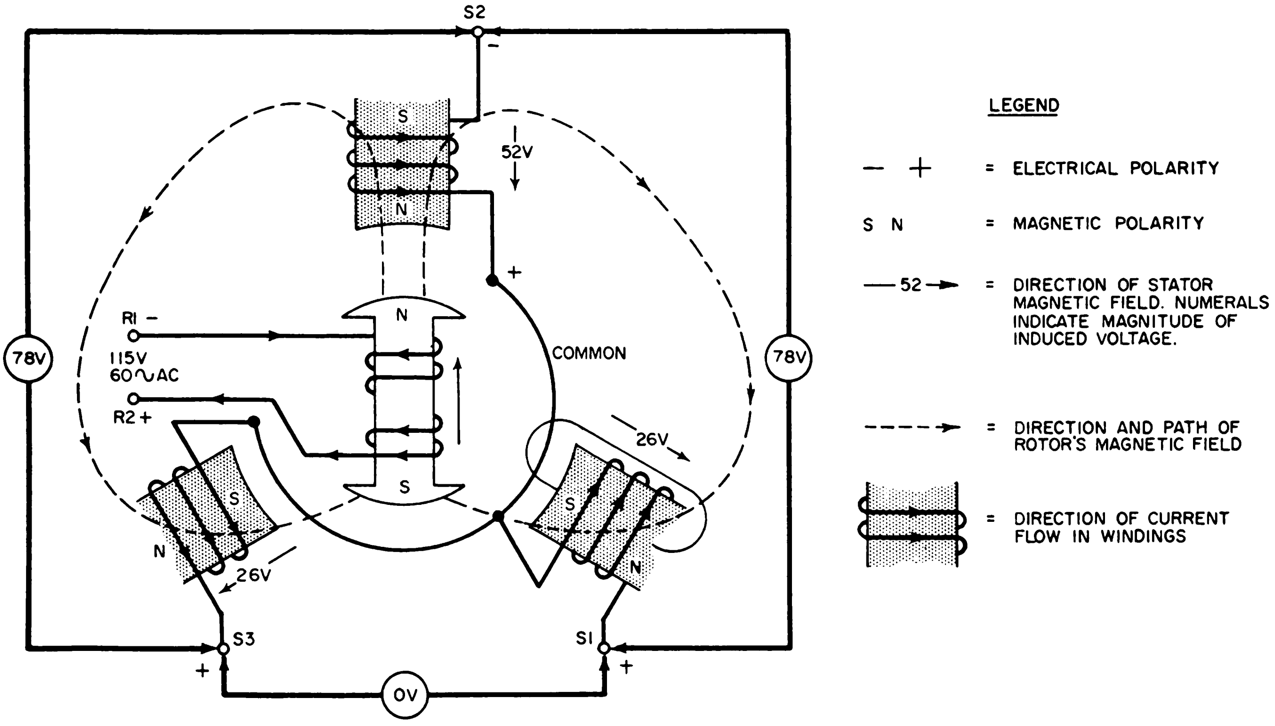
3. They have a rotor winding. (A rotating winding which corresponds to the other winding of a transformer)

Synchros sense position in one of three ways:

1. The position of the rotor in relation to a reference point (mechanical information).
2. The voltage on the stator winding in relation to a predetermined reference voltage (electrical information).
3. The voltage on the rotor winding in relation to a predetermined reference voltage (electrical information).

As you know, torque transmitters and receivers are energized with alternating current at their R1-R2 leads. The turns ratio between rotor and stator is such that a MAXIMUM of 52 volts for 115-volt units or 6.8 volts for 26-volt units is produced in any one stator winding.

Figure 11-3 shows a synchro, either a torque transmitter or receiver, with 115 volts a-c, applied to its rotor. The synchro is shown with a rotor angle of zero degrees. Rotor angle is measured from the longitudinal axis of the rotor to the axis through the center of the S2 winding. The axis of the S2 winding is the


S2
-
S
52V
N
+
N
R1 -
115V
60∿AC
R2 +
COMMON
78V
78V
26V
S
S
N
N
26V
S3
S1
+
+
0V
LEGEND
— + = ELECTRICAL POLARITY
S N = MAGNETIC POLARITY
—52→ = DIRECTION OF STATOR MAGNETIC FIELD. NUMERALS INDICATE MAGNITUDE OF INDUCED VOLTAGE.
- - - -→ = DIRECTION AND PATH OF ROTOR'S MAGNETIC FIELD
= DIRECTION OF CURRENT FLOW IN WINDINGS

167.785

Figure 11-3.—Synchro voltages, rotor at zero degrees.

standard reference point, and it's called the ELECTRICAL ZERO point. All rotor angles are measured from this reference. The voltages on the stator windings at this position of the rotor are the reference values.

CLASSIFICATION OF SYNCHROS

We can classify the more common types of synchros by their function, size, and the supply voltage and frequency. As you know, synchros are part of a synchro system. The function of the system determines the type synchros in it. If the synchro system provides a mechanical output (torque), which does the actual positioning of a load, it is a torque system. If it provides an electrical output which is used to control the power that does the mechanical work, it is a control system. Hence, synchros can be classified by the function they perform in the system. Table 11-1 lists the military abbreviation, inputs, and outputs of the more common functional classifications of synchros. Note that the table does not indicate that a CT can transmit to another CT. This, however, is possible and is done in some fire control equipment.

IDENTIFICATION OF SYNCHROS

Synchros that you will most likely encounter as an FTM are identified by a military standard designation code. Military standard synchros conform to specifications which are uniform throughout the armed services.

Table 11-1.—Synchro functional classifications

Functional Classification	Military Abbreviations	Input	Output
Torque Transmitter	TX	Rotor positioned mechanically or manually by information to be transmitted	Electrical output from stator identifying rotor position supplied to torque receiver, torque differential transmitter, or torque differential receiver
Control Transmitter	CX	Same as TX	Electrical output same as TX but supplied only to control transformer or control differential transmitter
Torque Differential Transmitter	TDX	TX output applied to stator; rotor positioned according to amount data from TX must be modified	Electric output from rotor (representing angle equal to algebraic sum or difference of rotor position angle and angular data from TX) supplied to torque receivers, another TDX, or a torque differential receiver
Control Differential Transmitter	CDX	Same as TDX but data usually supplied by CX	Same as TDX but supplied only to control transformer or another CDX
Torque Receiver	TR	Electrical angular position data from TX or TDX supplied to stator	Rotor assumes position determined by electrical input supplied
Torque Differential Receiver	TDR	Electrical data supplied from two TDX's, two TX's or one TX and one TDX (one connected to rotor, one to stator)	Rotor assumes position equal to algebraic sum or difference of two angular inputs
Control Transformer	CT	Electrical data from CX or CDX applied to stator; rotor positioned mechanically or manually	Electrical output from rotor (proportional to sine of the difference between rotor angular position and electrical input angle)

12.3.28

ilitary Standard Designation Code

This designation code identifies standard syn- hros by their physical size, functional purpose, nd supply voltage characteristics. We will use vo standard synchro designations, 18TR6 and 6CTB4a, as examples to explain the code. The rst two digits indicate the diameter of the syn- hro in tenths of an inch, or to the next higher nth. Thus, an actual dimension of 1.75 inches ecomes 18. The first letter indicates the general unction of the synchro and of the synchro system: for control; T for torque.

The next letter indicates the specific function f the synchro, as follows:

LETTER	DEFINITION
D	Differential
R	Receiver
T	Transformer
X	Transmitter

he letter B following the preceding letters dicates that the synchro has a rotatable stator.

The number after the letters stands for the erating frequency:

6 for 60 Hz
4 for 400 Hz

ne lower case letter is a modification des- nation. Successive modifications are in alpha- tical order.

Thus, the 18TR6 is a torque receiver with a Hz supply voltage and a diameter of between 71 and 1.80 inches. The 16CTB4a is a control ansformer for use in a 400 Hz system. It s a rotatable stator, and a diameter between 51 and 1.60 inches. The lower case "a" indicates at the synchro has been modified once.

Type designations for all standard synchros e assigned by this code. Synchros for use in rcuits supplied by 26 volts are clasified in e same way, except that the symbol 26V is pre- ed to the designator. Otherwise, a 115 volt urce is assumed for the synchro system. Note at in table 11-1 only the functional designator given. This is often the practice in OPs and schematic diagrams. The complete identifica- n is normally given in the physical descrip- n section of the OP.

In some texts synchro transmitters, TX, e called generators, and receivers, TR, e called motors.

SYNCHRO ALIGNMENT

The primary function of a synchro system is to transmit information between remote units. The information is represented in the synchro transmission circuits as electrical potentials and currents which vary with the angular position of the transmitter's and the receiver's rotor as measured with respect to their stators. We can say then that the information as represented by electrical values in the circuits is in fact a measure of the angular displacement of the rotor from a reference point established by the stator. Hence, as previously mentioned, a synchro is basically a postion-sensing device. Therefore, to receive the transmitted information correctly there must be a reference point common to both synchros and a common unit of measure used in both instruments.

To clarify this we will use a simple torque system as illustrated in chapter 5 (fig. 5-49). The TX rotor is coupled to a gear train and thus is mechanically restrained; its stator is stationary in its mounting. The TR rotor is free to turn; its stator, however, is stationary in its mounting. As you know, the axis of the S2 coil is the mechanical and electrical zero reference position of a synchro. Hence we have a common point within the synchros from which the angular displacement of the rotors can be measured. But if the synchro system is to transmit a quantity properly, it must be interaligned with the instruments. In the system in the figure, this means that when we place the TX's dial on zero, which represents the value of the quantity in the instrument, the synchro must be at its zero position. Plainly the same is true for the TR and the receiving instrument; when the synchro is on zero, the dial should read zero. If the dials are identical, you can see that the synchros are aligned to identical reference points. This is true although the receiver's reference is at some distance from the transmitter's. When these relationships have been established, the quantity on the TX dial can be transmitted correctly between the instruments by the synchro system.

Whatever the synchro system, either torque or control, the mechanical and electrical reference points must be aligned. All synchros can be considered fundamentally as transducers, in that they convert the input from an electrical signal to a mechanical signal, or vice versa. The input and output signals of a CT are electrical; but remember that its rotor is positioned mechanically. A review of the operation of synchro differentials, TDX and TRX, will show that they also are transducers. The point is that the electrical alignment of synchros must be correlated with their mechanical alignment.

Mechanical Alignment

We are concerned here with the mechanical alignment of a synchro system with the quantity to be transmitted as it is represented in the transmitting instrument and with the quantity as delivered by the synchro to the receiving instrument. Since these instruments are usually located at a distance from each other, the synchros are aligned individually to common reference lines.

To align a synchro system, the first step is to establish the reference lines so that they coincide, or are parallel. This is the mechanical alignment. As previously mentioned, the electrical axis of the S2 winding of a synchro is the reference line from which the rotation of its rotor is measured. Thus, a synchro has a built-in reference line. The position of the S2 winding is the connecting link between the mechanical alignment of a synchro with the instrument, and the electrical alignment of the synchro system.

The synchro's mechanical input is assigned a reference value or position for alignment purposes. This value is normally the zero position of the quantity in the instrument. Some quantities, however, are assigned an arbitrary value as a reference point for alignment. Synchros that transmit range, for example, may be aligned at 10,000 yards. In this manner, negative values of the quantity are avoided.

We now have established two reference lines, one in the synchro and the other in the instrument. If we place the mechanical input (or output) of the synchro at its reference value, we can say that the two reference lines are coincident if the synchro rotor is at its electrical zero position. Let's see why this is true. Any quantity which can be made to vary linearly with the angular motion of the synchro rotor can be transmitted by a synchro system. (It does not matter that a quantity is basically linear, such as range and speed; as long as a change in the quantity will change the synchro rotor position a proportional amount, it can be transmitted by synchro.) Thus if the input is at zero and the synchro rotor is at zero, the reference lines are coincident.

If the synchro rotor is not at the electrical zero position, the synchro must be adjusted. (We will cover the electrical zero of a synchro next.) This is done by physically moving the synchro stator in its mounting or by adjusting the rotor by its mechanical input.

Electrical Zero

In the Basic Electricity text we considered the terminal voltages of a synchro to explain synchro operation. From this study we have established the fact that for any given rotor position there is a definite set of stator voltages. Each type of synchro has a combination of rotor position and stator voltages which is called its electrical zero. The electrical zero condition is the reference point for the alignment of the synchro. We have defined the electrical zero in a torque system as the condition in which the axis of the rotor is lined up with the axis of the S2 winding. Look back at figure 11-3. In this illustration you can see that two such positions 180° apart are possible. As shown in the diagram, the rotor is at the electrical zero position, but if it were turned 180° we could still say it is lined up with the S2 winding. Let's see what is the electrical difference between these two rotor positions, and expand our definition of electrical zero.

In both the 0° position and the 180° position, the terminal voltage between S1 and S3 is zero. However, in the 0° position the voltages from S2 to S3 or from S2 to S1 are IN PHASE with the voltage from R1 to R2, while in the 180° rotor position the voltage from S2 to S3 (or S1) is 180° out of phase with the rotor voltage.

The electrical zero position is, therefore, completely defined as the position of the rotor in which the voltage between S1 and S3 is zero, and the voltage from S2 to S3 is in phase with the voltage from R1 to R2.

Since there is a natural tendency to overlook or to assume the obvious, which in this case is the basic rules of electricity and magnetism used to explain synchro operation, it will be helpful as an exercise to check the values in figure 11-3. To prove the electrical zero condition as represented by the values in the figure we will summarize the rules.

1. A resultant magnetic field must always oppose the inducing magnetic field, (Lenz's law). We can use this law to determine the direction of current flow in the stator windings.

2. With the direction of current flow known, the left-hand rule can be used to determine magnetic pole established in the stator.

3. Next we can use the formula

$$Es = Emax \times \cos \theta$$

to determine the voltages induced in the stator windings. In the formula, Es is the voltage induced in a stator winding of a synchro, and Emax is the maximum voltage that can be induced in a stator. In a standard 115 volt, 60 Hz synchro, Emax is 52 volts. Theta (θ) is the angle between the rotor and the axis of the stator winding. You should commit this formula to memory.

Electrical Zero in a Control System

The electrical zero position of the transmitter in a synchro system is identical to the TX or TR in a torque system. The receiver in the control system, however, must be described in a different manner. The output of a CT is the voltage induced in the rotor from the stator. A control transformer (CT), as the name implies, is basically a transformer. Maximum transformer action takes place when the windings or resultant fields of a transformer are parallel to each other. Hence, the electrical zero of a CT can be defined as follows:

With a set of voltages on the stator which represent the zero reference signal, the output of the rotor is minimum. (Normally it is not possible to obtain an absolute zero output due to flux leakage. The leakage is slight and will not distrub the control system, but we will use null rather than zero to describe the electrical zero position.) At its electrical zero position, the axis of the CT rotor is at a right angle with the axis of the resultant stator field. As in the case of the TX, it is possible for the rotor of a CT to be 180° out and still obtain null voltage. The rotor is in the correct electrical zero position if, when the rotor is turned slightly in a counterclockwise direction, the voltage between R1 and R2 is in phase with the voltage between S2 and S1 or S3.

Zeroing Procedure

The procedure used to adjust a synchro to its electrical zero position depends upon the tools you have and how the synchro is connected in the system. Each synchro is adjusted as an individual unit, but its interconnection with other units in the system must be considered. The Military Standardization Handbook, Synchros, Description and Operation, MIL-HDBK-225 (AS) (which supersedes United States Navy Synchros, OP 1303) covers methods for adjusting all types of synchros under various conditions. In this discussion we will cover the setting of synchros to electrical zero with a voltmeter.

One of the major considerations in zeroing a synchro is whether its rotor is free to turn or not. The synchro handbook covers separate methods for synchros with their rotors free to turn and for synchros with restrained rotors. The voltmeter method, however, can be used in either case. An electronic or precision voltmeter having a 0 to 250 volt and 0 to 5 volt range should be used. On the low scale the meter should be able to measure voltages as low as 0.1 volt.

There are two major steps in the zeroing procedure of a synchro. First, the coarse or approximate setting is determined, and, second, the fine setting is made. The coarse adjustment is a check between the correct setting and a setting 180° out. Recall from the discussion of electrical zero that the difference between the two positions determines the phase relation between the voltages on S2 to S1 (or S3) and on R1 and R2. The voltages are in phase when the rotor is at its electrical zero position, and 180° out of phase when the rotor position is 180° away from electrical zero. Hence the coarse check provides a means to determine the phase relation between the supply voltage and the induced voltages in the S2 and S1 stator windings. We will show you later exactly how this is done.

Standard synchros have an arrow stamped on the stator frame and a reference line scribed on the rotor shaft. With the synchro input on zero or the reference value, the alignment of the arrow and the line on the rotor will set the synchro on approximate zero. Thus, with standard synchros, this is the coarse check.

The alignment of a synchro system would logically start at the origin of the quantity being transmitted. For example, assume that you wish to align the synchro system which transmits director train. Naturally you would start at the director where this quantity originates. The first step in the alignment would be to set the director exactly on zero train. Next, you would set the director's train transmitters on their electrical zero position. With the transmitters on zero you can now set each receiver to its electrical zero. Since director train is a basic quantity there will be many receivers in the system. But each receiver can be adjusted as an individual unit since the electrical zero position is common to the whole system.

With this much out of the way we can now get to the meat of the topic—how to zero the different types of synchros. Remember, there are alternate methods not covered here.

Zeroing a CX or TX

Control transmitters (CX) and torque transmitters (TX) are functionally and physically identical. Therefore, they are zeroed in the same manner. The zeroing procedure is broken down into steps as follows:

1. Carefully set the quantity whose position the CX or TX transmits in its zero or reference position. This should place the synchro at its electrical zero position.

2. Deenergize the synchro circuit and disconnect the stator leads. Set the voltmeter to its 0- to 250-volt scale and connect it into the synchro circuit as shown in figure 11-4A. Figure 11-4B shows the equivalent circuit. Many synchro systems are energized by individual switches. Hence the instrument may be off but the synchros energized. Be sure the synchro power is off before working on the connections.

3. Energize the synchro circuit and turn the stator or rotor until the meter reads about 37 volts (15 volts for 26-volt synchros). This is the coarse setting and positions the synchro approximately on electrical zero. While doing this step, check that the quantity has not moved off its reference position.

4. Deenergize the synchro circuit and connect the meter as shown in figure 11-5.

5. Energize the synchro circuit and adjust the rotor for null, or minimum voltage. The final voltage reading should be taken on the 0- to 5-volt scale of the meter. After the synchro has been set and the adjustment secured, recheck the quantity's position and the meter reading.

Zeroing a TR

In many installations a torque receiver (TR) has a free rotor. A synchro with a free rotor can be zeroed by a simple method with no special equipment needed. This method, called an electric lock, requires only several short pieces of wire to be used as jumpers. Even they can be eliminated if the synchro leads are long enough. Essentially all you need is a source of electricity.

Figure 11-6 shows the synchro connections for an electric lock. S1 and S3 are connected together; therefore, the voltage between them is zero. S1 and S3 are then connected to R2. S2 is

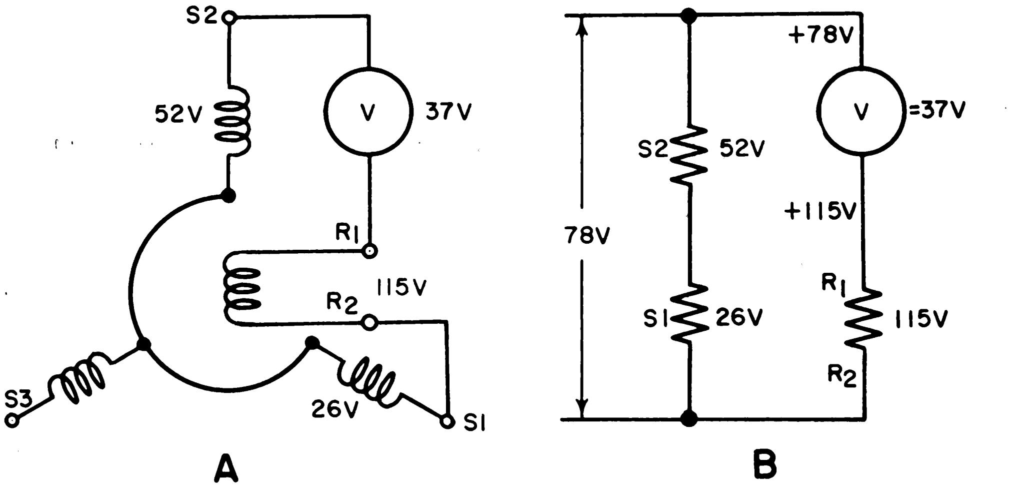


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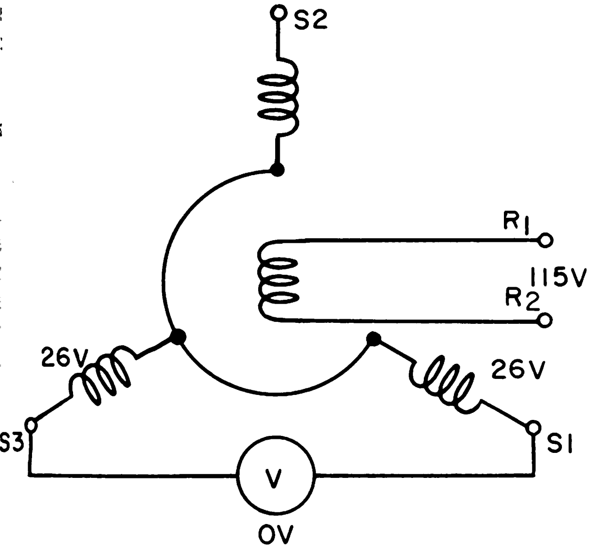
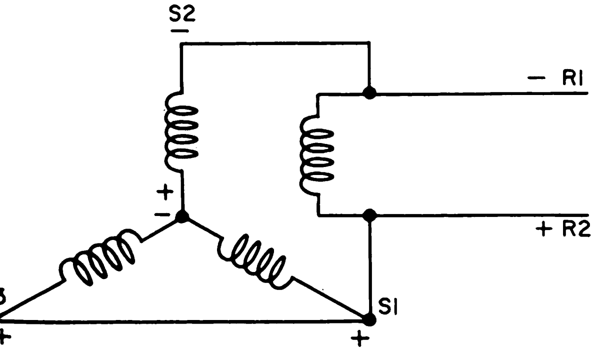
Figure 11-4.—Coarse zero check for a TX or CX.



1.120.1

Figure 11-5.—Fine zero check for a TX or CX.

umpered to R1; therefore, both have the same hase. There is a similarity between this method f zeroing a synchro and the definition of elecrical zero. When power is applied to the synchro, he rotor will snap to the electrical zero position. low you can align the dial, pointer, or any other evice which is associated with the synchro, to s reference position. But do it quickly—take o longer than TWO minutes. Remember, the ntire line voltage, 26 or 115 volts, is dropped cross the stator windings, which are now in arallel with the rotor winding.



1.119A

gure 11-6.—Connections for an electric lock.

The electric lock can be used only with synchros whose rotor is free to turn. If the rotor is not free, the voltmeter method, as described for the TX, may be used. A simple check on the common electrical zero position of a synchro system can be done with a jumper. Put the transmitter and receiver on zero and intermittently jumper S1 and S3 at the receiver. The receiver should not move. If it does, the transmitter is not on zero and should be rechecked.

Zeroing a CT

The rotor of a control transformer (CT) is not free to turn; therefore, we will use the voltmeter method. The zeroing procedure is as follows:

1. Position the unit associated with the CT at its zero or reference position.
2. Remove the connections from the CT and reconnect as shown in figure 11-7.
3. Adjust the rotor or stator to obtain minimum voltage reading. This is the coarse check.
4. Reconnect the CT and meter as shown in figure 11-8 for fine setting.
5. Adjust the CT for a minimum or null voltage reading. After the adjustment is secured, check to make sure the meter reading has not changed.

Here again, as in the electric lock procedure, the 115- or 26-V supply is dropped across the

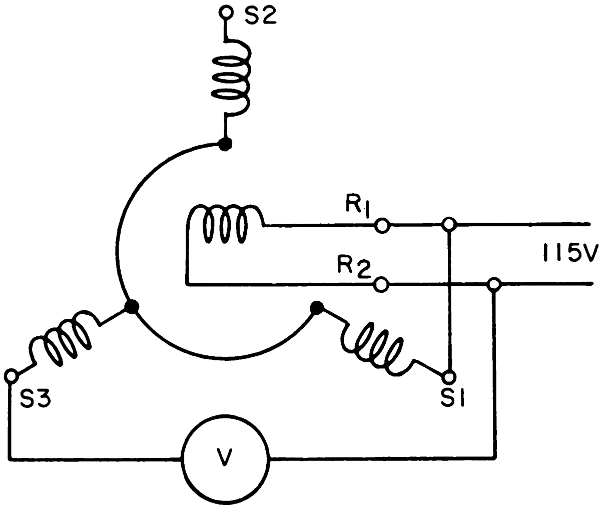


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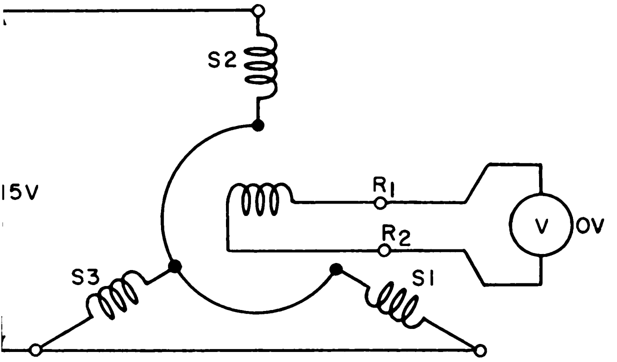
Figure 11-7.—Coarse zero check for a CT.



1.120.1
Figure 11-8.—Fine zero check for a CT.

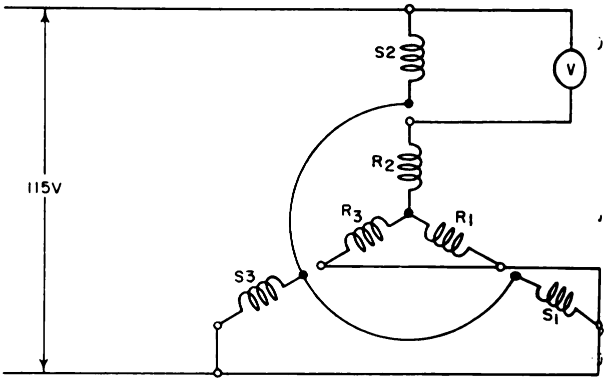
ator windings. Consequently, there is the danger overheating and permanent damage to the 'nchro if it is connected in this manner for more an two minutes. This danger can be avoided a 78-V instead of 115-V, and a 10.2-V instead 26-V supply is used. Unfortunately a 78-V 10.2-V supply is not usually obtainable on e job.

lectrical Zero for Differentials

A differential modifies the information in e synchro system. Therefore, a differential is zero if the information can pass through it ithout a change in value. In the electrical ero position the axes of the R2 and S2 windings oincide.

To zero a torque differential transmitter, 'DX), a control differential transmitter (CDX), a torque differential receiver (TDR), using voltmeter, proceed as follows.

1. Set the quantity whose position the TDX CDX transmits accurately in its zero or eference position.
2. Disconnect the differential, set the volteter on its 0- to 250-volt scale, and connect shown in figure 11-9.
3. Turn the stator until the meter reading minimum. The differential is now on aproximate electrical zero. This is the coarse tting.
4. Reconnect as shown in figure 11-10 for the ne setting. Turn the stator until a null reading obtained. The meter should be on the 0- to -volt scale for the null voltage reading. Secure e stator and recheck the null voltage.

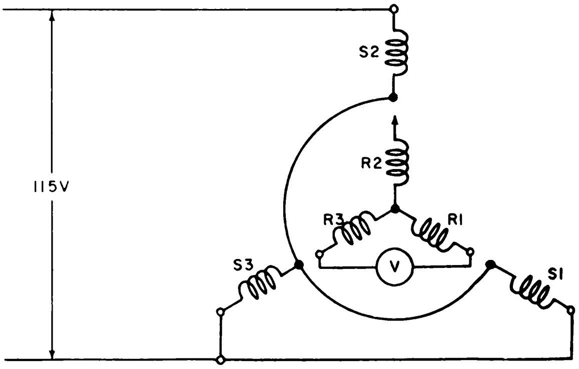


12.277
Figure 11-9.—Coarse zero check for TDX or CDX.

SYNCHRO CAPACITORS

When a synchro differential or a control transformer is connected to a transmitter, the transmitter must supply the stator currents to the other synchro. Remember, the rotor of a differential or a control transformer is not energized by the line voltage. Therefore, their stator windings are inductive loads on the transmitter. In a-c circuits the current through a coil lags the applied voltage by an amount of time determined by the coil impedance. The effective power of a circuit in which the voltage and the current are out of phase is less than the volt-ampere product.

A capacitor connected across the coil will reduce the out-of-phase current in the circuit.



12.27
Figure 11-10.—Fine zero check for a TDX or CDX.

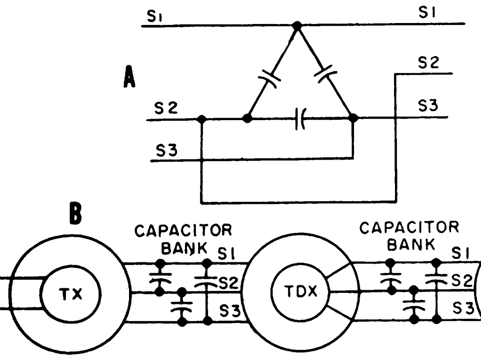
If the capacitive reactance of the capacitor is equal to the inductive reactance of the coil, the two will cancel. The resultant current in the circuit would be determined solely by the d-c resistance of the coil winding.

A synchro capacitor bank consists of three equal delta-connected capacitors (fig. 11-11A). The capacitors are connected in parallel with the stator windings of a synchro differential or control transformer (fig. 11-11B). The stator currents drawn from the transmitter are reduced, and when the synchros are in correspondence, the transmitter supplies only the current due to the windings' resistance.

The rotor of a torque receiver is energized by line voltage. Currents present in the stator circuits of a TX-TR synchro system are a result of a voltage difference between the stators. If the synchros are in correspondence, there is no voltage difference and hence no current in the stator circuits. Therefore, capacitors are not required in a TX-TR synchro system.

SYNCHRO SYSTEM ACCURACY

Fire control systems are extremely accurate, but a system's accuracy can not be greater than the accuracy of any of its parts. A system's accuracy depends on the accuracy of its instruments and their associated data transmission systems. Therefore, the accuracy of a synchro system which transmits data between instruments is important.



12.279

Figure 11-11.—Synchro capacitors.

Synchro Errors

A perfect synchro has never been made. Synchros will always contain some errors due to manufacturing inaccuracies and assembly. For every physical position of a synchro rotor there is a corresponding electrical position. For example, if the rotor of a perfect synchro transmitter is at 30°, as shown in figure 11-12, the voltages you will read across the stator terminals will be as follows:

S1 to S2—90 volts and 180° out of phase with R1-R2.

S1 to S3—45 volts and in phase with R1-R2.

S2 to S3—45 volts and in phase with R1-R2.

These stator voltages and phase relationships are unique for 30° rotor position. (See fig. 11-12B.) These quantities will not be obtained at any other position of the rotor. But, as noted before, synchros are not perfect. Any difference between the actual physical position of the rotor and the electrical position is known as electrical error. (Sometimes the electrical error is called static accuracy.) It is possible to get the voltage readings and phase relationships listed above when the rotor of a real synchro is at, say, 30° and 18 minutes. Therefore, the synchro has an electrical error of 18 minutes. This is a typical error for a control transformer. The electrical error for synchro transmitters can be that high, but usually it is in the order of 8 to 15 minutes.

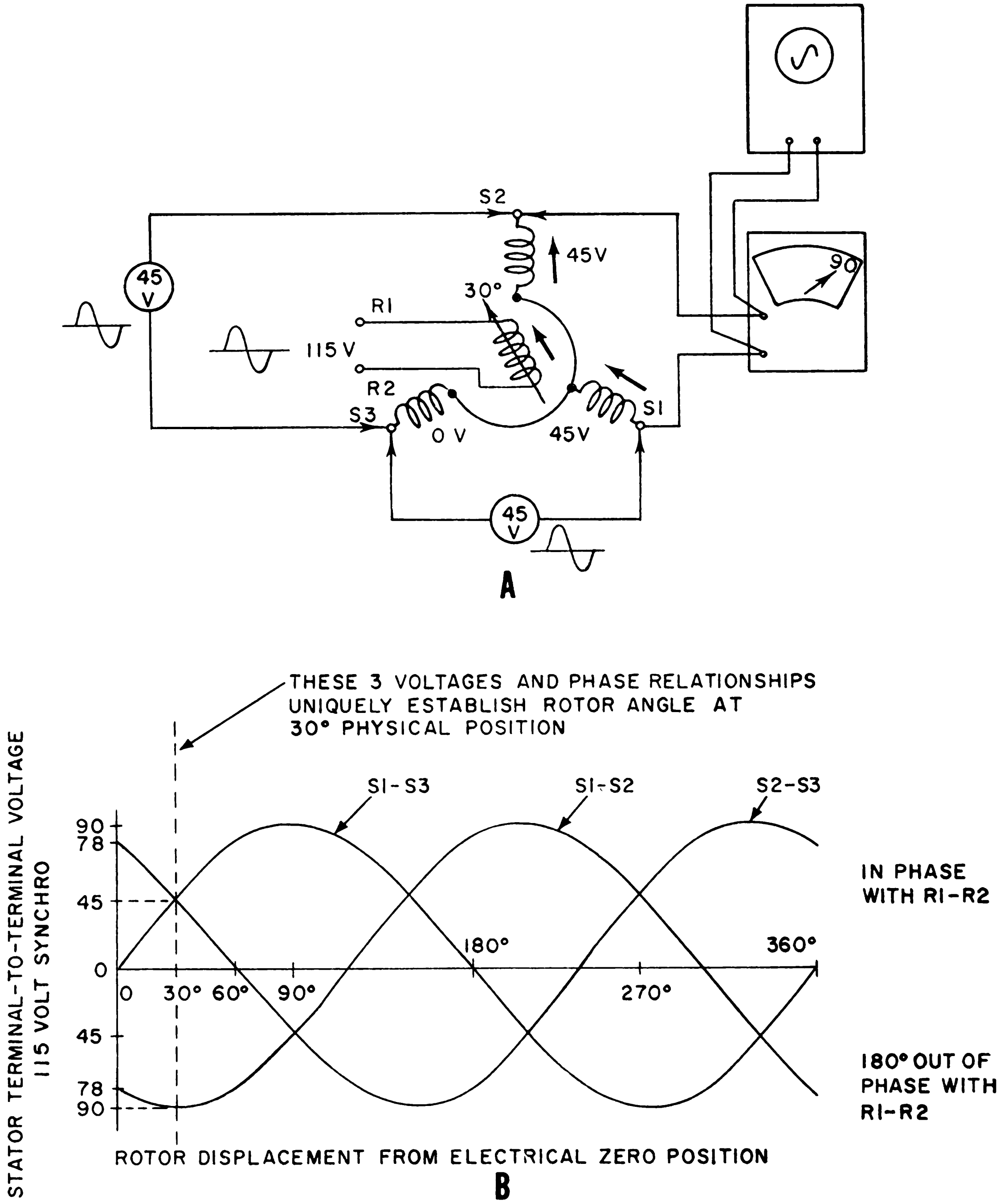
Consider a practical synchro system consisting of a control transformer and transmitter like the system shown in figure 11-13. If both units have an electrical error of 18 minutes, the total possible electrical error is 36 minutes, or a little over half a degree.

What can cause errors in synchros? Briefly, here are some of the causes:

1. It is impossible to make the three stator windings the same. Each winding could have a different number of turns, for example.

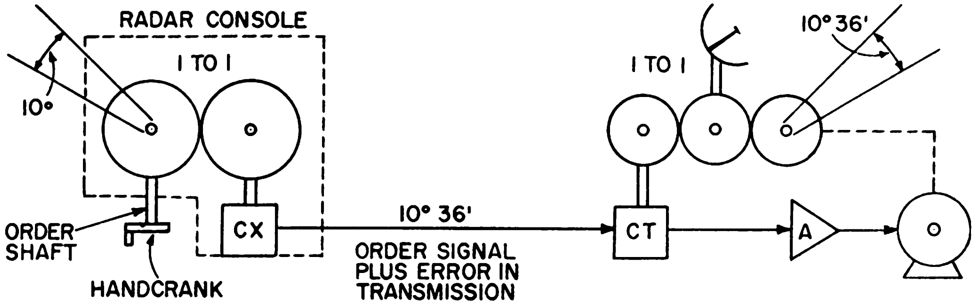
2. The rotor and stator assemblies must be exactly round. If they are slightly elliptical, an electrical error results.

3. The rotor of a synchro must be put in the exact center of the stator bore. If the rotor is off center by just a small fraction of an inch, then there will be an electrical error.


S2
45V
45
V
30°
R1
115 V
R2
S3
0 V
45V
S1
90
45
V
A
THESE 3 VOLTAGES AND PHASE RELATIONSHIPS UNIQUELY ESTABLISH ROTOR ANGLE AT 30° PHYSICAL POSITION
S1-S3
S1-S2
S2-S3
STATOR TERMINAL-TO-TERMINAL VOLTAGE
115 VOLT SYNCHRO
90
78
45
0
45
78
90
0
30°
60°
90°
180°
270°
360°
IN PHASE WITH R1-R2
180° OUT OF PHASE WITH R1-R2
ROTOR DISPLACEMENT FROM ELECTRICAL ZERO POSITION
B

83.71

Figure 11-12.—Synchro electrical error.



55.15

Figure 11-13.—Error in synchro transmission.

A servo is only as accurate as its error tector. If there are electrical errors in the rvo's data transmission system, the servo tput will reflect the electrical error. Now :'s see how electrical errors show up in a ngle synchro system.

The pictorial diagram in figure 11-14A shows synchro transmitter and control transformer nnected in the conventional way. We will sume it is a perfect system. It has no elec- cal error. Both units are perfect. Notice rticularly that all gear ratios are 1:1. That , if we turn the transmitter handcrank one volution, the transmitter rotor will turn one volution (360°). Similarly, if you turn the handcrank one revolution, the control trans- rmer rotor will turn one revolution. Further- ore, assume that the dials on both rotor gear es are so accurate that we can read angular sition of the respective rotor in minutes of c as well as degrees of rotor angular position.

Since we have a perfect system, if we put rotor of the transmitter on zero, and then n the crank at the CT end of the system, voltmeter connected across the CT R1-R2 ds will read zero when the CT dial reads ro. If we turn the rotor of the transmitter to as read on the CX rotor dial, and then turn control transmitter handcrank until the volt- ter reads zero volts, a glance at the CT dial l show that it reads exactly 5 degrees. You repeat this experiment for every position of dial and the result will be that when the nsmitter rotor is at a selected position, the rotor will be at the same position when the tmeter reads zero. In other words, we have fect transmission of data.

But now look what happens when we use actual chro units in the system. Assume the synchro system contains an accumulated electrical error of, say, 36 minutes. The pictorial diagram in figure 11-14B shows the same setup as before. But instead of perfect synchros, we have replaced them with ones that have an electrical error of 18 minutes each. If we put the dial of the transmitter at zero, we will transmit what we think is an electrical signal proportional to zero degrees. But to get a null (minimum or zero reading of the voltmeter), the CT rotor must turn through an angle of 36 minutes. At null it is obvious that the two rotors are not in the same angular position. The transmitter rotor is at its zero position and the control transformer rotor is 36 minutes away from zero. Now turn back to figure 11-13. Assume that the data transmission system shown there also has a 36-minute electrical error. If the radar operator turned the CX rotor shaft to the position corresponding to zero antenna elevation order, the power drive servo would position the antenna at zero degrees and 36 minutes. The antenna is certainly not at the ordered position. It is close to it, maybe, but it is not exactly on it. For this reason the system we are talking about here is called a COARSE system. It transmits approximate angular position information because the system contains electrical error. But antenna power drives must receive very accurate aiming information so that the radar beam can be pointed in the right direction. Therefore, an additional synchro system, called the FINE system, is used along with the coarse system. To show how a fine system works we can make one out of the coarse system we've just talked about simply by changing gear ratios.

In figure 11-14C we have done just that. Instead of a 1:1 gear ratio between the synchro rotors and their handcranks we have installed

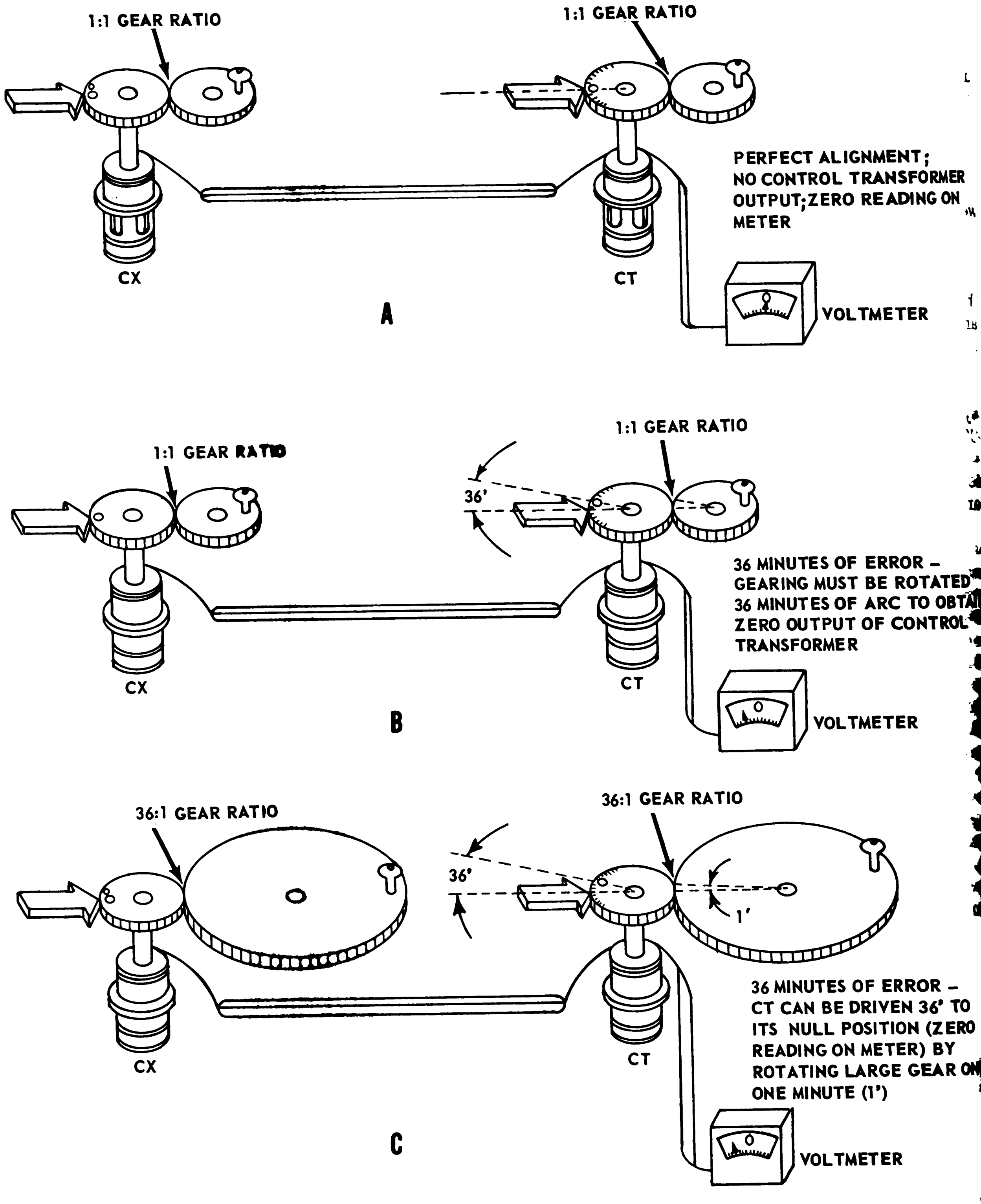

1:1 GEAR RATIO
1:1 GEAR RATIO
PERFECT ALIGNMENT; NO CONTROL TRANSFORMER OUTPUT; ZERO READING ON METER
CX
CT
A
VOLTMETER
1:1 GEAR RATIO
1:1 GEAR RATIO
36'
36 MINUTES OF ERROR – GEARING MUST BE ROTATED 36 MINUTES OF ARC TO OBTA ZERO OUTPUT OF CONTROL TRANSFORMER
CX
CT
B
VOLTMETER
36:1 GEAR RATIO
36:1 GEAR RATIO
36'
1'
36 MINUTES OF ERROR – CT CAN BE DRIVEN 36' TO ITS NULL POSITION (ZERO READING ON METER) BY ROTATING LARGE GEAR ON ONE MINUTE (1')
CX
CT
C
VOLTMETER

Figure 11-14.—Electrical error in a synchro system.

gears with a ratio of 36:1. If we turn either handcrank one revolution, its associated rotor will turn 36 times. Also it follows that if we turn either crank one minute, then the rotor geared to the crank will turn through 36 minutes of arc. Now mentally place both dials at zero. Assume hat we have a 36-minute electrical error in the ynchro system. With the increased gear ratio, ve only have to move the control transformer andcrank one minute to null the voltmeter even hough we have a 36-minute error in the system. So, by increasing the gear ratio we have reduced he effect of the error 36 times. Remember, in n identical situation using a coarse (1:1 ratio) ystem we had to move the CT rotor 36 minutes o get system null.

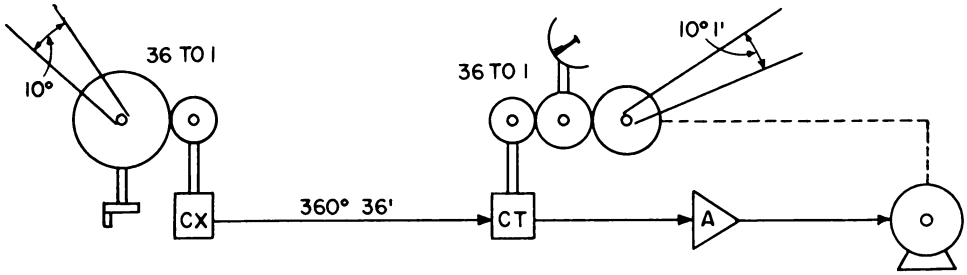
In the preceding discussion about synchro ystem electrical error we manually turned the T handcrank which moved the CT until we aw a zero reading on the meter dial. Now et's replace the human operator with a servo nd show how increased gear ratios improve the ccuracy of the synchro system and its associated ervo. The diagram in figure 11-15 shows an ntenna power drive servo controlled by a fine ynchro system. Assume there is a 36 minute ccumulative error in the synchro system. If e put the input shaft (CX rotor shaft) at its ERO physical position and the antenna at its ero position, the servo will drive the antenna rough a ONE minute angle. But, because of e 36:1 stepped-up gear ratio between the tenna and the CT's rotor, the rotor of the T will turn 36 minutes, cancelling out the 36—inute electrical error. At this point, the volte at the amplifier input is zero, and the servo ops. The important point is that the antenna s moved only one minute even though the ror in the synchro transmission system is 36 inutes. Or, you can say the angular position between the input and output of the system (data transmission system and servo) is one minute. If we had used a coarse transmission system with a 1:1 gear ratio, the difference between the input shaft and the output shaft would have been 36 minutes when the servo stopped driving the antenna.

DISADVANTAGES OF 36:1 SYNCHRO TRANSMISSION

The main disadvantage of the 36:1 transmission is that the servo is no longer self-synchronous. In the 1:1 transmission system the output shaft is synchronized with the input shaft at only one point. In other words, there is only one position the output shaft can assume which will allow correspondence between the rotors of the CT and the transmitter. However, in the 36:1 transmission system the output shaft can be in correspondence at 36 different positions for any one position of the input shaft. For example, if the rotor of the transmitter is at 0° (see fig. 11-15), the output shaft, and consequently the antenna, could be synchronized at 0°, at 10°, at 20°, and so on, in steps of 10 degrees. In each of these positions of the output shaft, the control transformer's output is zero, thus bringing the CT into false correspondence with the transmitter in each case.

COMBINING THE FINE AND COARSE SYSTEMS

Although the fine system provides high accuracy in a power drive servo, it is seldom used by itself since, as you have seen, it does not provide true synchronization of the input and output at all times. We certainly would not want the antenna pointed at 80 degrees,



55.16

Figure 11-15.—Decreasing synchro transmission error by increasing gear ratio.

when the synchro transmitter rotor shaft was at, say, 10 degrees. Therefore, the fine system is always combined with a coarse system. The fine synchro system provides a very sensitive control at times when the error between the order signal and the servo output is small. Since this is a 36-speed synchro, however, it can bring the antenna to any one of 36 positions. It is the job of the coarse synchro system to bring the antenna close enough to the true synchronous position so that it is within the range of the fine synchro. You learned how control was switched between coarse and fine when you studied synchronizing circuits in chapter 9.

ZEROING DUAL-SPEED SYNCHRO SYSTEMS

If a fine and a coarse synchro are used to define a quantity's position, the synchros must be zeroed together. As pointed out earlier, the coarse synchro will define the position of a quantity to within the range of the fine synchro's capability to define the position more precisely. From this it can be reasoned that the coarse synchro provides the first significant figure in the numerical description of the quantity's position. Obviously then the coarse synchro is zeroed first. When zeroing the synchros in a system, consider each synchro as an individual unit. Thus, one of the methods already described can be used to zero the coarse synchro.

The next step after the coarse synchro is zeroed is to zero the fine synchro. A fine synchro provides the next significant figure in the numerical description of the quantity's position. The fine synchro is zeroed as an individual unit. But the quantity's zero or reference position has already been established with respect to the coarse synchro's electrical zero position. Hence, when you zero a fine synchro, the setting of the coarse synchro and the quantity must be set together.

There are a few three-speed synchro systems. These systems are zeroed in the same manner as the dual-speed systems. First, establish the zero position for the synchro which provides the most significant figure, and work down to the least significant figure. Just remember that all the synchros in a system must have a common electrical zero position.

If the synchros in a dual-speed system do not have a common zero position, there is a definite possibility that the system will not synchronize properly. This is not hard to visualize. For example, assume that the director train receivers in the computer are not zeroed together. The coarse synchro would drive the director train system to its zero position. Since, however, this position is not the fine synchro's zero position, it would drive director train to its zero position. Hence, the two receivers would buck, and the director train in the computer would oscillate between the two zero positions.

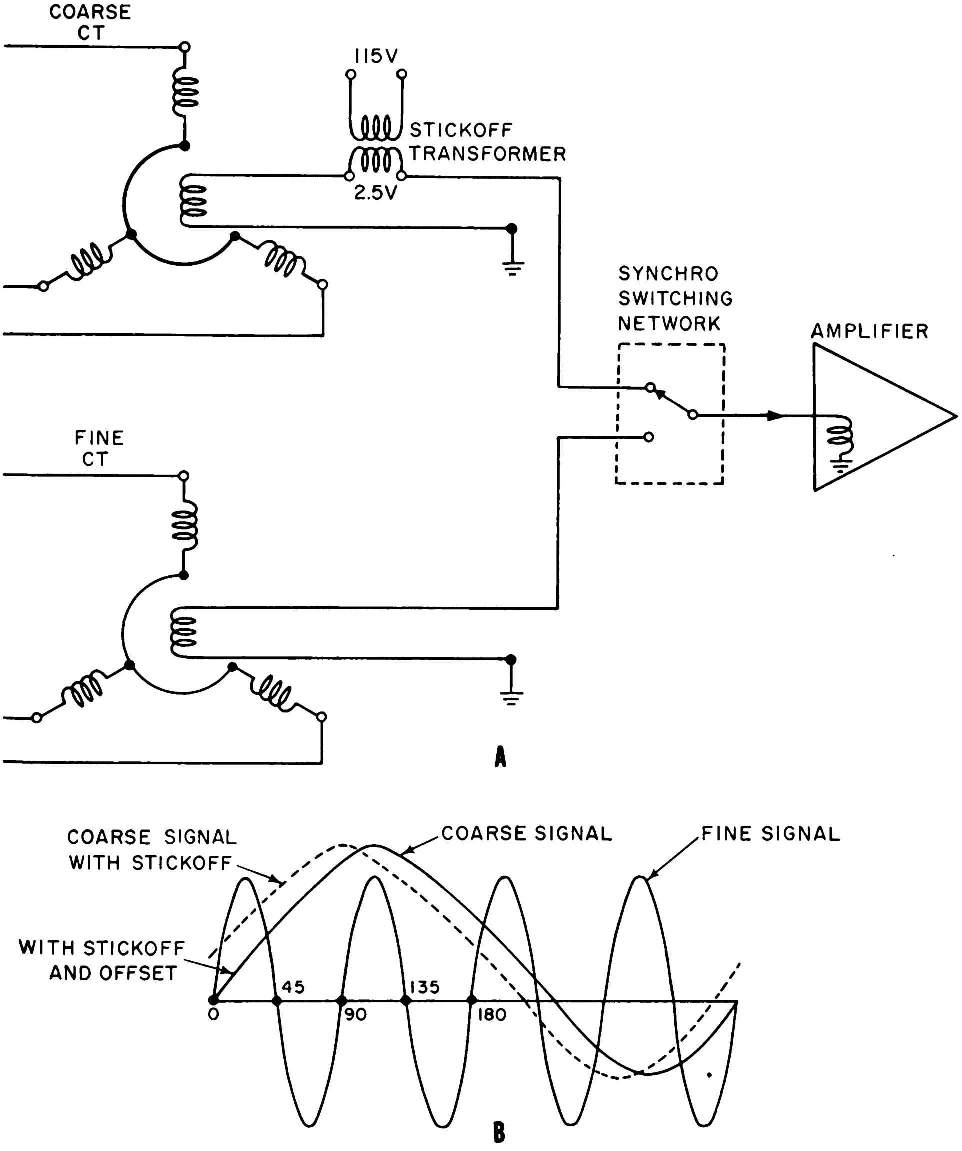
The fact that the receivers in a synchro system are zeroed together leads us into the next subject.

STICKOFF VOLTAGE

A servosystem will stop driving when the error signal is zero. A CT, however, has two positions 180° apart where its output is zero. Thus a servosystem controlled by a CT can synchronize at either position. This is possible in a dual-speed synchro system with an even speed ratio. Since both receivers are zeroed together both would be at the true correspondence and the false correspondence positions together. Hence a servosystem could not distinguish between the two positions. In fire control systems where remote and often unattended servosystems are used, the possibility that a false synchronization could occur must be eliminated.

As mentioned previously, no CT is perfect, and each has an inherent dead space. But the fine signal has little or no dead space to speak of. Therefore, the slightest change in the signal or movement of the servosystem's response will bring the fine CT out of its dead space, Once out of its dead space the fine CT will cause the servosystem to drive. You might think then that we do not have a false synchronization problem. But suppose that when the system is energized the transmitters and receivers are close to being 180° apart. The coarse signal would be too weak to assume control of the system, and the fine CT would have control. Therefore, the servosystem would drive until the fine signal is zero and remain there. The servosystem could not sense the difference between 180° and zero synchronization.

In order to make all positions distinguishable, a "stickoff" voltage (sometimes call anti-stickoff), is applied to the coarse sig In figure 11-16A the secondary winding of stickoff transformer is shown in series with coarse CT output. The voltage induced in t secondary of the transformer in effect shifts t electrical zero position of the coarse CT. T coarse CT is rezeroed and is offset from t fine CT by an amount equivalent to the sticko



12.280

Figure 11-16.—Stickoff voltage in coarse signal circuit.

ltage. This makes the coarse and fine CT lt out zero volts at zero degrees but not at 0° (fig. 11-16B). Now, the two positions are stinguishable to the servosystem.

TROUBLESHOOTING A SYNCHRO SYSTEM

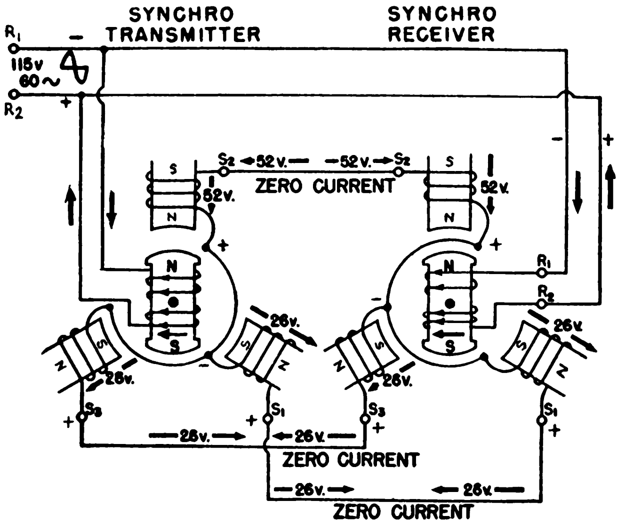
Here we will discuss the symptoms produced casualties in a synchro system. In a later chapter of this course, troubleshooting techniques such as the methods used to find a ground, short, or open in an electrical circuit are covered. Therefore, those techniques will not be covered at this time.

Since a knowledge of operation is a basic requirement of maintenance, we will summarize synchro operation as related to troubleshooting. This will be a review of synchro action since the theory of synchro operation is covered in Basic Electricity.

Information is transmitted in a synchro system by voltage variations in the stator circuits. A synchro receiver compares its stator voltages with those of the transmitter's stator; the amplitude and phase of both sets of voltages are related to the zero reference position. A receiver reacts to a difference in voltage values by producing a torque, in a torque system, or passively, in a control system, by an induced voltage in its rotor. The receiver reproduces the conditions present in the transmitter to reconstruct the information. Hence, a synchro system is a suppressed-carrier transmission system. The modulation of the signal voltages represents the information being transmitted.

Let's look at a torque system (fig. 11-17). At correspondence the induced voltages in the two S1 coils are equal; the induced voltages in the two S2 coils are equal; and the induced voltages in the two S3 coils are equal. Since the stator voltages are bucking and equal, they cancel each other. The result is: no resultant voltages on the stator windings and NO CURRENT in the stators.

But remember that the transmitter rotor is turned and held in position mechanically, whereas the receiver rotor is free to turn. Now, if the two rotors are NOT displaced by the same amount, the voltages across S1-S1, S2-S2, and S3-S3 are NOT equal. And the unequal voltages set up currents in the stator windings. These currents create stator flux fields that exert TORQUE on the rotors. Result—the transmitter rotor remains stationary because it is held mechanically, but the receiver rotor is turned by the torque. The torque turns the receiver rotor until its position corresponds to that o the transmitter rotor. Thus the receiver follow every move of the transmitter.



12.170.1
Figure 11-17.—Torque synchro system.

Obviously the receiver's supply voltage mus be identical to the transmitter's. Normally bot are supplied from the same source. A synchro by the way, is not a three-phase device, thoug you may get that impression from the 120° spacing of the stator windings. Synchro supply i from a single-phase, a-c power source.

In explaining synchro operation terminal voltages were discussed. Their most important practical purpose, however, is to find the electric zero position of the rotor. Since the stato voltages are proportional to the position of t rotor, stator voltage readings are an aid i troubleshooting. There is a definite set of stato voltages for each position of the rotor. Therefor a synchro's operation can be checked by compari its voltage readings with its rotor positio For example, a voltmeter connected between and S3 will read minimum voltage at the and 180° positions of the rotor. Maximum volta readings will occur at the 90° and 270° position of the rotor.

Because synchros have a common electric zero position, identical casualties will produ identical symptoms in all synchro system Therefore, we can relate an electrical casual to the mechanical movement of the rotor, a by observing the behavior of a synchro's movements we can localize a casualty to a particula circuit. For example, in a properly zero torque system, a short circuit from S1 to will cause the receiver to stop following signal when it is at 0° or 180°.

We have assured that there is no mechani trouble when we observe the receiver's mot This, of course, is not a good assumption should be checked. Remember that a sync generates little torque. To be sure the synch is not jammed mechanically, deenergize t system and turn the rotor by hand. It sho rotate freely throughout its operating arc. T ease with which the rotor should rotate is

atter of judgment, but experience will soon
ach you how to tell whether a synchro is free
jammed. It is a poor practice to use the
al to rotate a synchro. The dial is made of
ht material, and is easily bent.

After the mechanical check, the torque pro-
ced by a synchro can be checked. At corre-
ondence the torque is zero. With the system
ergized, a slight rotation of the motor should
rease the torque. Vary the input to the re-
iver, so as to turn it through its complete
erational arc, stopping at approximately 60°
ervals. Observe how the receiver follows the
nal, and at each stop check the torque.

ENS, SHORTS, AND REVERSALS

In a synchro system the transmitted infor-
tion is reconstructed in the receiver by the
tor's resultant magnetic fields acting on the
or's magnetic fields. The stator windings are
sically located 120° apart. Therefore, it is
ical to assume that each stator winding has
arc in which it exercises a predominant
e in reconstructing the transmitted infor-
tion. Hence casualties such as opens, shorts,
reversals can be correlated with the trans-
tted signal position and the reaction of the
eiver. In the Military Standarization Hand-
k; Synchros, Description and Operation, MIL-
BK-225 (AS); casualty symptoms are tabulated
this manner. Since this synchro handbook
uld be available to you, the tables will not
repeated here.

The maintenance techniques for finding a
ualty in an electrical circuit are covered
r in this manual.

NCHRO CONTROL SYSTEMS

In a synchro control system the rotor of
CT is not energized by the supply voltage.
CT stator windings are connected in parallel
the CX stator windings. Thus, the currents
sent in the CT stator are proportional to
currents in the CX stator. The magnetic
ds in the CT are a reproduction of the CX
or fields. The output of a CT is the voltage
uced in its rotor. A comparison of the signal
t with rotor voltage will check the operation
CT.

TECTIVE DEVICES

Most synchro systems have one transmitter
ransmit information to several receivers. These receivers are located at the various fire control stations throughout the ship. Because all the receivers of each system are in parallel, a fault such as an overload or short circuit in one instrument affects the operation of the entire system. When trouble occurs in such a system, it is difficult to determine which unit is faulty. The use of overload and blown-fuse indicators provides a means of locating the faulty instrument. Various types of blown-fuse indicators are used. These devices usually employ small neon-glow indicators in parallel with the fuse element. Overloads are indicated by a trouble light that is operated by a small transformer located in the switch panels on the fire control switchboard.

REFERENCES

The theory, application, classification, and maintenance of all types of synchros are covered in more detail in Military Standardization Handbook; Synchros, Description and Operation, MIL-HDBK-225 (AS); and in Basic Electricity, NAVEDTRA 10086-B.

RESOLVER SYSTEMS

You have already learned something about resolvers in chapters 5 and 6 of this training course. As you know, a resolver is a variable transformer capable of unlimited rotation. In its most common form it consists of a stator and rotor, each wound with two separate coils placed precisely at right angles to each other. The two stator windings are normally stationary, and serve in some applications as the primaries. However, they may be used as secondary windings in other types of resolvers. The rotor windings serve also as secondaries or primary windings, depending on type and application of the resolver. The rotor assembly can be rotated with respect to the stator windings. Some resolvers have separate connections for each winding; others use one common lead for the primaries and another for the secondary. The common lead is usually connected to ground. Some types have extra windings for feedback, and others leave out either one primary winding or the secondary.

RESOLVER APPLICATION

Resolvers are used extensively in computers, coordinate converters, in some radar sets, in weapon direction equipment, target designation equipment, and for data transmission. These devices perform electrical computations involving (1), resolution, (2) composition, and (3) combination. You are familiar with the first two operations through your studies in chapter 6. However, let's briefly review them.

RESOLVER OPERATION

If you apply an alternating voltage, labeled E in figure 11-18A, to the rotor winding, the output voltages from the two stator windings will be sine and cosine functions respectively of the angular position (θ) of the rotor. In other words, as shown in figure 11-18, they will be equal to E sine (θ) and E cosine θ. Referring to the vector triangle in part B of figure 11-18, where the vector E is drawn as the resultant or hypotenuse of the triangle, you can see that the resolver actually breaks down or resolves vector E into its two rectangular components. This process is called resolution of vectors.

You can look at vector resolution from another point of view. In the previous example a vector was given in polar coordinates. The length of the vector represents magnitude and an angle θ direction. The resolver breaks down the vector into rectangular components. Now, in the place of the word components, you can substitute the word coordinates. This term is just as correct as components. Therefore, you can say that another function of a resolver is to conver coordinates—in this case polar to rectangular

Still another point of view can be considered You know from your study of trigonometry tha if you are given one side of a right triangle an an adjacent angle, you can find the other tw sides. In our example, the resolver was give one side (E, the hypotenuse) and an adjacen angle (θ). The output of the resolver is th length of the other two sides. Thus, you can sa that a resolver can solve for two unknowns in right triangle.

Now, let's make our resolver work back wards. If you apply two in-phase voltages to th stator windings with the polarity and magnitud shown in figure 11-19A and then rotate the roto by hand, or a servo, to the given angle, the ou put from the rotor will be 5 volts. The outp voltage is the vector sum of the A and B voltage This process is called composition. The geomet of the problem is shown in figure 11-19B. Aga note the transformation of information fro one coordinate system to another. In this cas rectangular coordinates are changed to pol coordinates.

Combination consists of performing resoluti and composition simultaneously. This requi the use of more than one resolver.

It can be seen from this discussion that th is a defeinite relationship between the mechanic input and the electrical outputs of a resolve Therefore, we can use them to develop analo scaled, signal voltages in data transmissi systems. Resolvers have this feature in comm

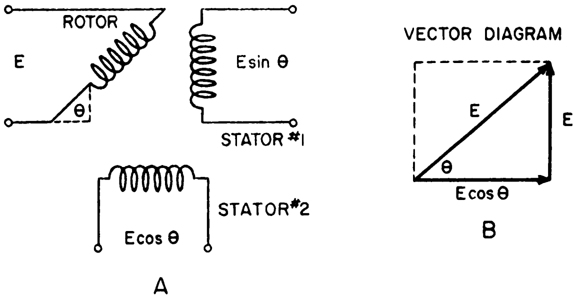


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Figure 11-18.—The resolution of an a-c voltage which represents a vector.

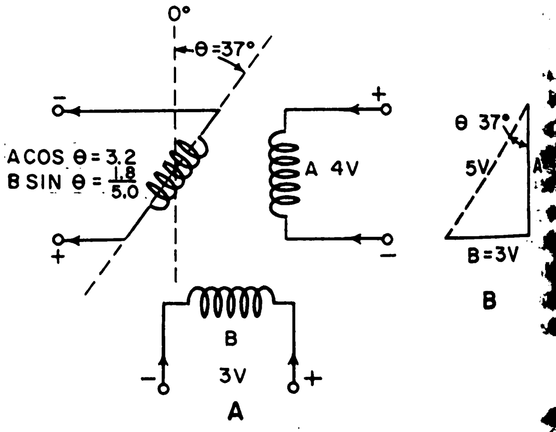

Figure 11-19.—Resolver composition.

with synchros, but resolvers are more accurate and much more versatile.

RESOLVER COMPENSATORS

Voltage regulation is very important because the resolver voltages represent functions and quantities in the fire control problem. If the voltage regulation is poor, the resolver will introduce errors into the problem. But resolvers are variable transformers, and changes in the angular position of the rotor will change the impedance or load as seen by the stator windings. Thus, the current in the resolver will vary and affect the magnitude and the phase of the resolver voltages.

The calibrating resistors shown in figure 5-34 are precision resistors that serve two purposes. First, they compensate for voltage inaccuracies in the winding and phase shifts introduced by load changes. Second, they are used to standardize the electrical characteristics of a resolver type.

To increase a resolver's accuracy, its input voltages are supplied through compensators. These are regulating circuits consisting of reactance and resistance components in series with the resolver windings. Their purpose is to make the input voltages independent of the varying current in the circuit.

BOOSTER AMPLIFIERS

To reduce the voltage regulation troubles in circuits where the output of one resolver is the input to another resolver, a booster amplifier is connected between the resolvers. The amplifier has a high input impedance and a low output impedance, and acts as an isolation circuit. It is essentially a power amplifier with approximately unity voltage gain and a zero phase shift. Thus, the amplifier can supply an appreciable amount of power to its output circuit while drawing only a negligible amount of power from its input circuit. Consequently, variations in the load are compensated for in the amplifier, and the signal voltage to the receiver resolver has the correct magnitude and phase.

There's one thing you'll find in every booster amplifier—nearly 100 percent negative feedback. That's what makes them voltage regulators. Negative feedback is used because of its ability to stabilize a circuit and maintain the gain constant under varying loads and d-c supply voltages.

ZEROING A RESOLVER

There are many methods used to zero resolvers. Each manufacturer has his own method. The method described below uses the basic principles underlying all the different resolver zeroing methods.

Before a resolver can solve a problem, it must have a reference position from which the input values are measured. This is the zero position of the resolver. The zero position of a resolver is determined by the angular relationship between the rotor and stator windings. Each stator winding must be perpendicular to a corresponding rotor winding. When this relationship is established, there will be no magnetic coupling between corresponding windings.

The absence of a magnetic coupling between corresponding rotor and stator windings is possible at two positions 180° apart. To ensure the correct position, so that the phase relationship between the rotor and stator is correct, the coarse zero test is made first. Figure 11-20A shows the connections for the coarse zero test. The voltage applied to the stator winding $S_1 - S_3$ is a reference voltage specified for the resolver. The two windings are connected in parallel by the voltmeter and the jumper. The voltmeter will read the applied voltage, plus or minus any voltage induced in the rotor winding. The jumper across the winding $S_2 - S_4$ is to eliminate any stray voltage that might originate from that winding.

To make the coarse zero adjustment, loosen the flange mounting screws of the stator. Looking at the rear (brush end), turn the stator counterclockwise. Stop turning when the voltmeter reads the input voltage, E. At this point you know the $R_2 - R_4$ coil has no induced voltage because the voltmeter reads the input voltage alone. This means that the $R_2 - R_4$ is approximately at right angles to $S_1 - S_3$, and the rotor is at coarse zero.

With the voltmeter reading the E voltage, turn the stator a little beyond coarse zero. The voltage at the voltmeter should INCREASE ABOVE E, because the voltage induced in the $R_2 - R_4$ coils adds to E. Be sure the voltage at the voltmeter increases to prevent zeroing at 180° out of phase.

The next step is to set the resolver on fine zero. Figure 11-20B shows you how to reconnect the jumper and voltmeter. Turn the stator so that the voltage on the voltmeter decreases,

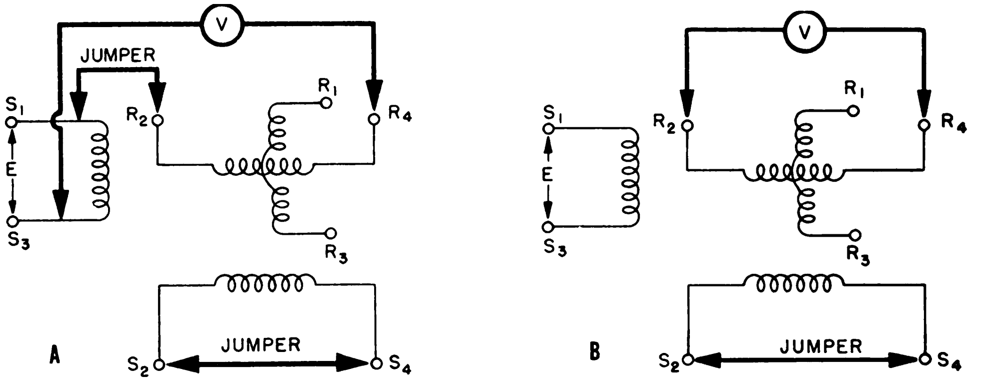

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Figure 11-20.—A. Coarse zero; B. Fine zero.

and keep shifting the meter to the lower scales until the minimum voltage reading is obtained. The minimum voltage reading means that R_2 - R_4 is exactly at right angles to S_1 - S_2, and the rotor is at fine zero. Recheck this voltage after you secure the mounting screws.

RESOLVER MAINTENANCE

The maintenance of resolvers consists mainly of testing and replacement. Internal repair of a resolver normally should not be attempted aboard ship. A resolver is a precision component, whose electrical characteristics are critical, and any deviation may result in excessive errors in the system. The procedures for testing resolvers are covered in your system or instrument OP. Here we will discuss the general principles involved.

The test run on a component is determined by the functions it performs in a system or circuit. Therefore, if we know the function and operation of a component, the test that checks it can be readily understood. This is elementary and, of course, will hold true for resolver tests. In fact, we could go back to the zeroing procedure and just about leave it at that, for resolver maintenance starts and ends with alignment tests.

If you understand how to zero a resolver, you will have no trouble understanding the operational tests of a resolver. The zero position is our reference point for these test. These mechanical inputs to the resolver are positioned at a known angle and a voltage reading is taken. The input voltage, which usually is a reference voltage set at a predetermined value, is checked first. Then the resolver's output voltages are read and the voltage values are listed in the OP. If you study them, you will find the output voltages are related to the input voltages by the sine and cosine functions of the angular input. For the test to be accurate, be sure the exact reference voltage is used. Moreover, if the wrong voltage is used, it is quite possible you will damage some of the components in the circuit. The OP will specify the type of meter to use in the test since the accuracy of the meter is an important consideration.

Frequently, the OP will list the resistance reading of the resolver windings. These are given for testing only; no repair aboard ship is intended. If it is necessary to replace a resolver, be sure the replacement is of the same type. The resolver's compensating resistors are used to standardize a resolver type. Therefore, do not attempt to adjust these unless the OP gives definite instructions on it. The same holds true for the resolver's compensating circuits.

STEP TRANSMISSION SYSTEM

A step transmitter and a step motor are used together to transmit angular motion between

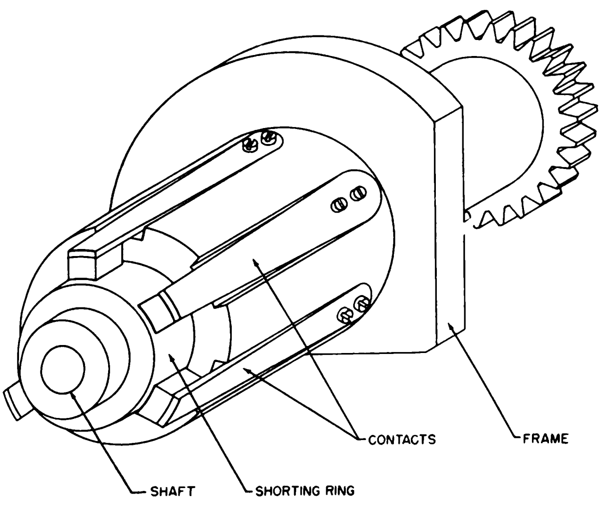

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Figure 11-21.—Step transmitter.

emote locations. The shaft of the step trans-
itter is rotated, and periodically switches a
-c excitation voltage from one pair of coils
another in the step motor. The step motor,
hich is the receiver in the system, responds
this varying excitation by rotating an amount
at is proportional to the transmitter's motion.

The step transmitter (fig. 11-21) has an in-
lation frame, a shaft, an eccentrically mounted
orting ring, and four contacts. The shorting
ng is surrounded by the four contacts, when are fastened to the ends of flat, conducting spring arms. Each spring is secured in a slot in the insulated frame. During a complete revolution of the step transmitter's shaft (fig. 11-22), brushes 1, 2, and 3 come in contact with the shorting ring in a sequence. But brush C is in contact with the shorting ring at all times. One side of the d-c supply voltage is connected through brush C to the shorting ring. As the shaft is rotated, one side of the supply voltage is connected to the other brushes in a definite order.

The stator of the step motor has six field coils spaced 60 degrees apart. The coils are connected in three groups of two coils each (fig. 11-22), with opposite coils being connected in series. One end of each pair of coils is connected to one of the brushes in the step transmitter. The other end of the coils is connected to the other side of the d-c supply voltage through a common lead. As the rotor of the step transmitter is turned, the circuits to the field coils in the step motor are energized in a sequence. A rotating stator field is produced in the motor. Since the field's rotation is determined by the brushes in the transmitter, the motor moves in increments or steps rather than smoothly.

The rotor of the step motor (fig. 11-23) is made of a mu-metal, soft iron, and has four projections in the form of a cross along its length. As the stator field rotates, the field's lines of flux cause the rotor to turn so as to provide a path of least reluctance for the magnetic field. Figure 11-23 graphically illustrates

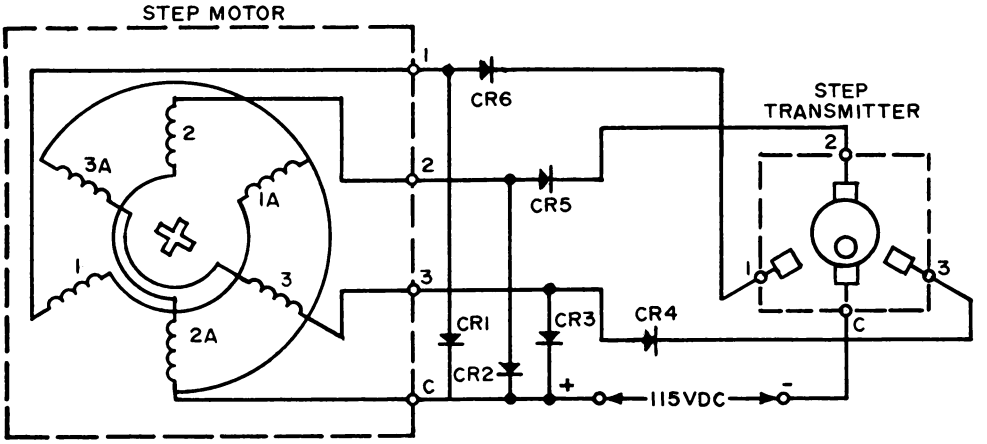

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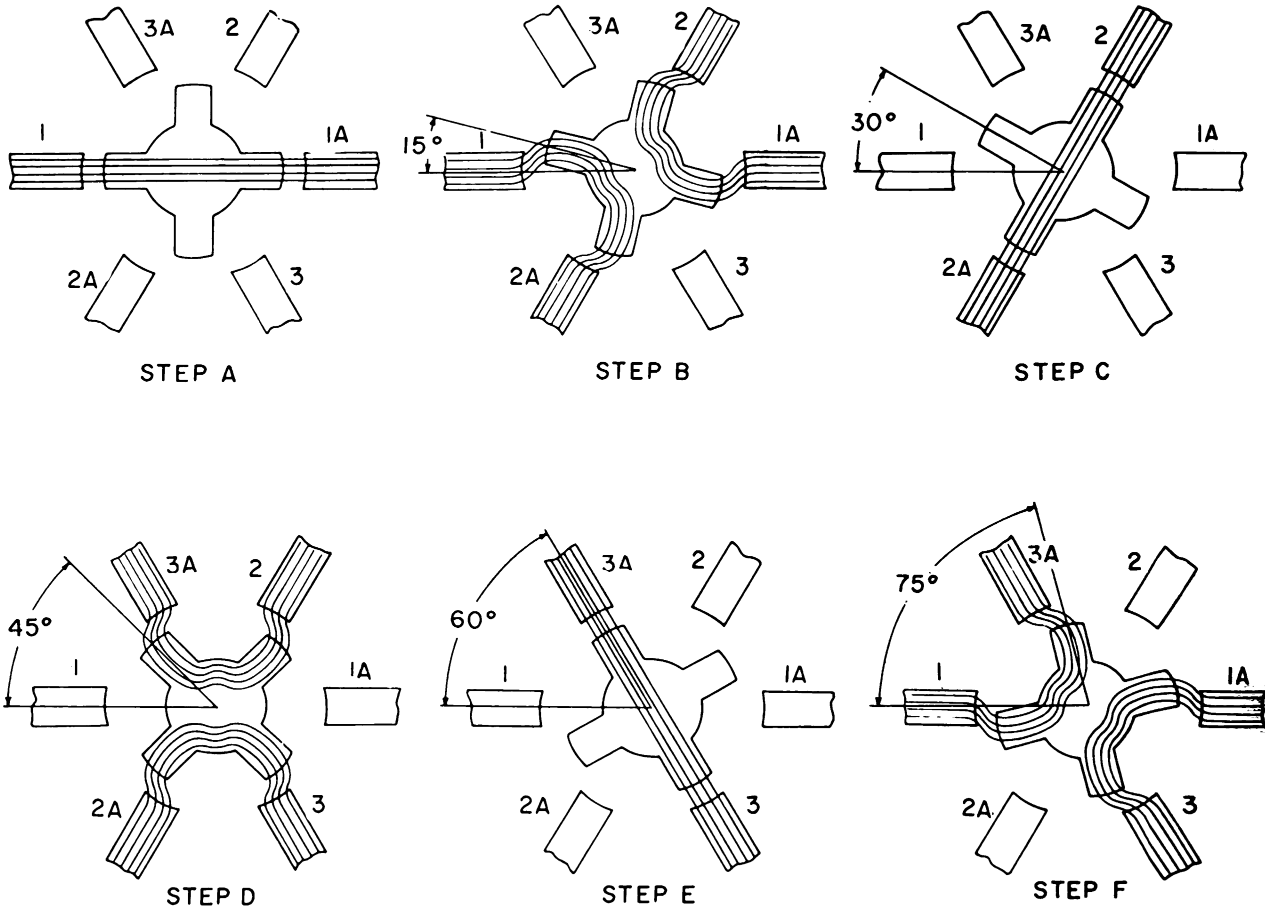
Figure 11-22.—Interconnections for a step motor and a step transmitter.



166.

Figure 11-23.—Step motor action.

the sequence of the steps, while table 11-2 lists the steps and the conditions that exist during a complete revolution of the step transmitter. Note that the step motor's rotation is only a quarter of the step transmitter's rotation.

Diodes are used with the step motor as spark suppressors (fig. 11-22). Diodes CR1, CR2, and CR3 act as a short circuit when a voltage is produced opposite to that applied to the coils of the step motor. If the coils of the step motor produce a voltage larger than that applied, diodes CR4, CR5, and CR6 appear open.

A step transmission system is not self-synchronizing and its limited number of steps does not permit a quantity to be transmitt smoothly. This type of transmission system cheap, rugged, and relatively powerful. It used where exact linear transmission is required.

BALANCED BRIDGE CIRCUITS

Balanced bridge circuits are used to trans information between remote instruments. T principles of operation are identical to the br circuits used in electrical measuring devi

Table 11-2.—Step by step summary of the action

Steps	Degrees of Transmitter Rotation	Contacts Made	Coils Energized	Position of Rotor Reference Pole
A	0-60	1	1 & 1A	0°
B	60-120	1 & 2	1 & 1A 2 & 2A	15°
C	120-180	2	2 & 2A	30°
D	180-240	2 & 3	2 & 2A 3 & 3A	45°
E	240-300	3	3 & 3A	60°
F	300-360	3 & 1	3 & 3A 1 & 1A	75°

Step A. Coils 1 and 1A are energized, and the nearest rotor pole is drawn into alignment.

Step B. Coils 1 and 1A and 2 and 2A are energized. There are 90° between rotor poles and only 60° between stator-field poles. Therefore, the rotor, in aligning itself so as to present the path of least reluctance, moves midway between the field coils, or a distance of 15 degrees.

Step C. Coils 2 and 2A are energized. The rotor moves an additional 15° to line up its poles with those of the field coils.

Steps D, E, and F. The rotor moves an additional 15° each step in the manner described above.

167.140

(Wheatstone Bridge) covered in Basic Electricity. A balanced bridge circuit consists of two identical potentiometers connected in parallel with a common source of supply (fig. 11-24). The wiper arms of the potentiometers are interconnected through a signal circuit which includes an input transformer in a servosystem. If the wiper arms are not at the same potential, current will flow through he signal circuit. The amount and direction of he current flow are determined by the potential difference of the wiper arms.

Assume that we wish to transmit range rate, which is measured in a radar receiver, to a computer. The device which measures range ate positions the wiper arm of the potentiometer n the radar receiver (fig. 11-24). The range rate servosystem in the computer will drive the ollowup potentiometer's wiper arm until there s no current in the signal circuit. This condiion will occur when both arms are at the same otential and hence at the same position on their otentiometers. Thus the followup wiper arm vill follow any movement of the signal arm.

Since range rate can be either negative or ositive, the potentiometers are grounded at heir centers. The grounded positions of the otentiometers represent zero range rate. The grounds constitute a phantom connection between the centers of the potentiometers. When the wiper arms are in the section of the potentiometers below the grounds, range rate is negative, while above the grounds range rate is positive. When the wiper arms are on the grounds the phantom connection shunts out the signal circuit.

DIGITAL TRANSMISSION SYSTEMS

Data in digital form is fast becoming an important factor in the missile fire control area. Digital ranging units have been developed for missile radar systems. Analog fire control computers are being replaced by digital computers. Some Weapon Control Stations already have operational digital computers for data processing. Therefore, a discussion of digital data transmission techniques is appropriate at this time. As you study these techniques, you'll find that they are closely related to information that was presented in chapter 7. In this chapter, we will enlarge upon that information and place greater emphasis upon the transfer of digital data between equipment.

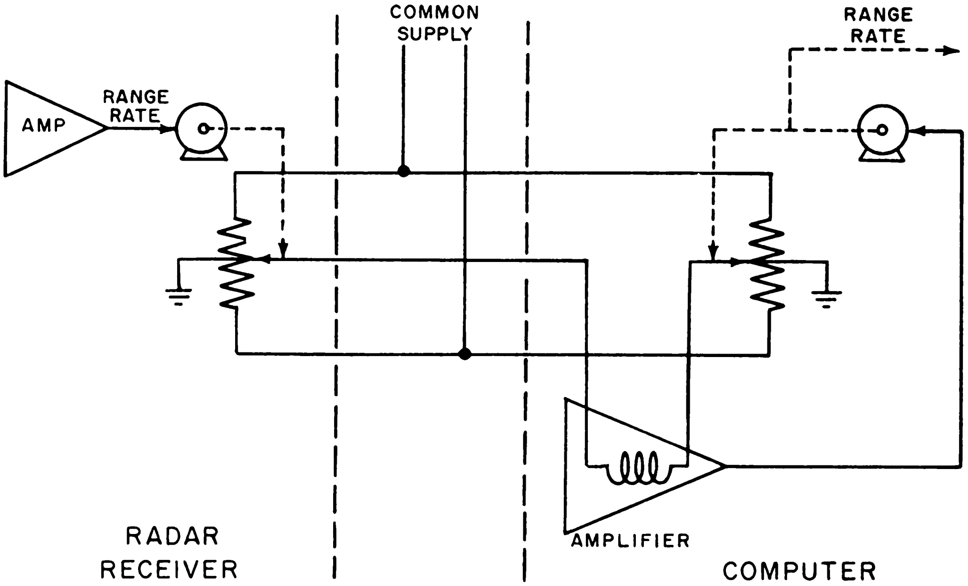


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Figure 11-24.—Balanced bridge circuit.

DIGITAL DATA REPRESENTATION

Before studying the methods used to ensure accurate transfer of data from equipment to equipment, it is first necessary to understand clearly the method used to represent data. To explain this we will consider a system which uses the two-level method of pulse representation.

Each computer word contains digits, the number dependent upon design. In figure 11-25A it is shown that a word contains a number of bits, again, dependent on design. Once the bits-per-digit and digits-per-word are established in a computer which uses a fixed word length, each computer word will contain the same number of bit positions. Thus, all words in a fixed word length computer are of constant duration.

Bit Parallel-Digit Parallel

The method of data transfer as illustrated in figure 11-25A is called the bit parallel-digit parallel or fully parallel method of transfer. With this method a word can be transferred (either recorded or written) in one bit-time. Obviously this method provides for fast transfer, but requires the use of separate lines (and associated circuitry) for each bit contained in the word.

Bit Parallel-Digit Serial

The method illustrated in figure 11-25B is called bit parallel-digit serial. To illustrate how this method of notation is derived, each bit has been assigned a number and it is understood that bits represented up and down the page are transferred simultaneously (four at a time) while bits represented across the page are transferred in sequential bit-times.

Bit Serial-Digit Serial

In the fully serial, or bit serial-digit serial, method of transfer (fig. 11-25C) all bits in the word (and, therefore, all digits) are transferred sequentially. All bits are transferred over a single line and use a single transfer circuit. Although circuit requirements are simplified by using this method, more time is required to transfer a single word.

Because of time consideration as discussed above, fully serial computers are not widely used. In many cases, however, fundamental timing techniques used in computers (both serial and parallel) are sometimes more easily or more clearly explained assuming serial operation and using serial circuitry. For example, if it were considered necessary to explain in detail the operation of all circuits used in the transfer of

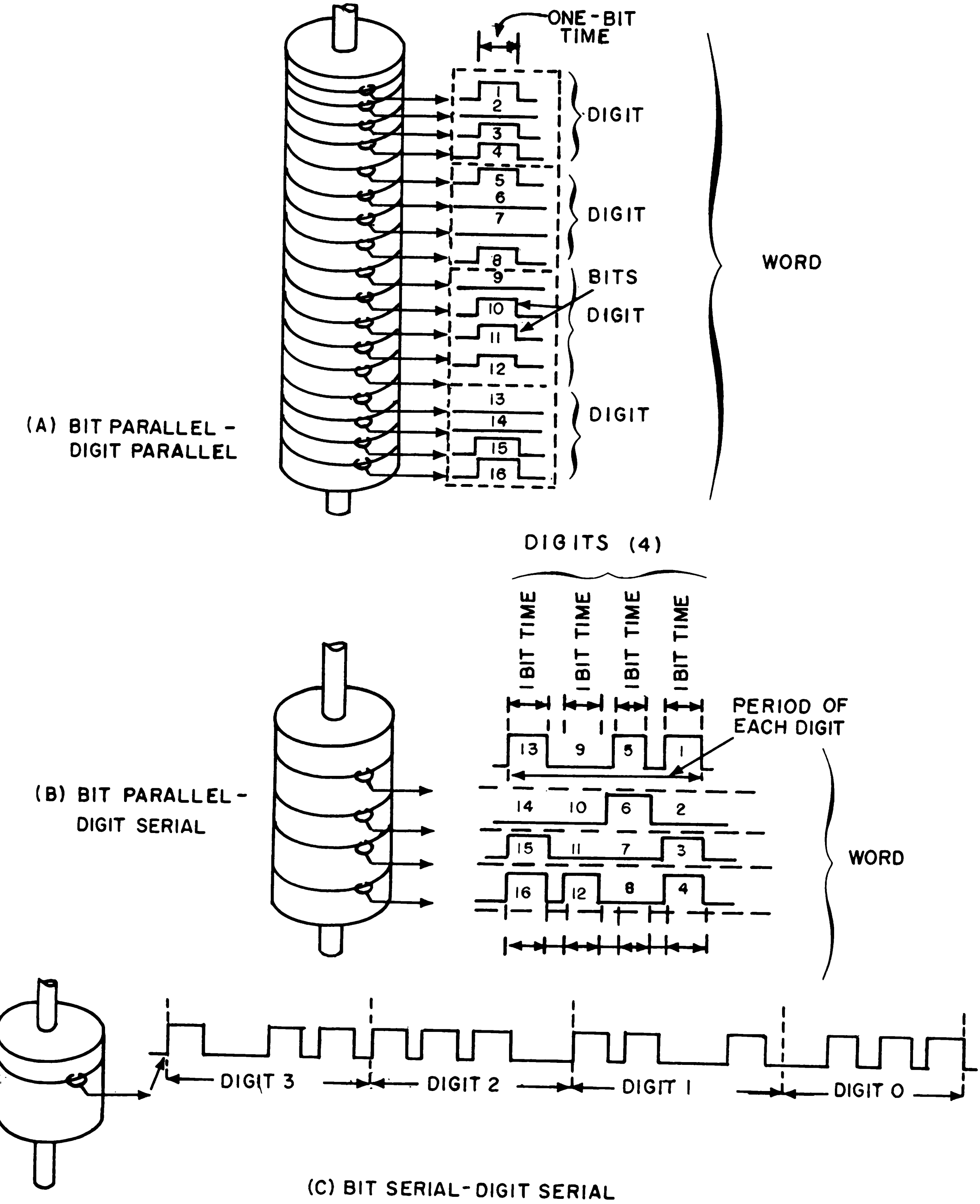

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Figure 11-25.—Methods of data transfer.

bit parallel-digit parallel data, it would be simpler to explain the action by using a single circuit and a single (recurring) bit input.

ANALOG/DIGITAL AND DIGITAL/ANALOG CONVERSIONS

Most of the equipment in today's fire control systems develop data in analog form. In order for a digital computer to communicate with equipment analogous in nature, a means of converting data from one form to the other is necessary. Conversion equipment is within the area of your responsibility so you must know conversion techniques. Basic conversion devices (encoders and decoders) were briefly presented in chapter 7. At this time, however, let's examine them in greater detail.

Analog-To-Digital Conversion

An analog-to-digital converter is defined as a device that receives an analog input and supplies a digital output. A converter of this type is capable of accepting instantaneous values of a constantly changing variable and expressing these values in incremental form. The converter may or may not perform some computation in addition to its primary function of data conversion.

The process of analog to digital conversions is not uncommon. Our minds make hundreds of analog-digital conversions each day. For example, if you ask a young child what time it is, he will probably look at a clock and tell you that the long hand is near the six and the short hand is near the four. The child is performing the function of data transmission, not data conversion. He is accepting the instantaneous value of the constantly moving hands of the clock, but he is transmitting the information in analog, not digital, form. The data which the child transmitted is converted into numerical values, in this case, 4:30. You, the inquirer, are therefore performing the analog-to-digital conversion, the child is not.

Care must be taken to avoid confusing truly digital readouts with others that merely appear to be digital. The needle of a voltmeter or the pointer on an automobile speedometer provides analog data by indicating the instantaneous value of volts or miles per hour in a constantly changing manner. It is only by reading these meters and assigning numerical values that a truly digital readout is obtained. Just as in the example of the clock, the human observer is serving as the analog-to-digital converter. Similarly, the type of data that is obtained from a micrometer scale or from the mercury column of a thermometer is analog in nature, until converted by the reader. The accuracy of each of these devices is, in large measure, a function of the ability of the reader to convert the information accurately from analog to digital form.

On the other hand, mechanical counters such as those commonly used to count the number of people entering a building provide a true digital readout. No great amount of skill is required for reading such a device because its accuracy does not depend on the reader, but upon its design. If each clock of the counter corresponds to a count of one, no amount of skill on the part of the reader will increase its inherent precision.

MECHANICAL TECHNIQUES.—Probably the simplest method of converting analog information, such as shaft rotation, into digital form is the obvious method of connecting the shaft through a gear drive to a decade counter. This process is sometimes called shaft rotation digitation, since each rotation of the shaft is explained in digital form. One common application of the gear drive and counter method of conversion is used by the mileage counter (odometer) of an automobile.

In addition to providing a digital readout from analog data, the odometer also performs some simple analog computing. The basic information is the rotation of a shaft. A gear train multiplies this by the correct constant to produce miles per revolution. The data are still in analog form. After multiplication, the data are summed by the counter and displayed in digital form to represent the total miles traveled. The original input is analog, the computing is performed by means of analog techniques, but the readout is digital.

This technique is also used in various other applications. Many airborne and ship-based analog computers used in bombing, navigation, or fire control applications, use this form of readout both for output indications and for an indication of input information that has been cranked in manually. Although this technique is simple and widely used, it is of rather limited value. It can be used for readout or readin purposes only. Since the digital output must be visually observed on the counter wheels, it cannot be used to feed another computer except through a human operator. In fact, this technique is not suitable for automatic operation.

Shaft-Position Digitation by Geared Counter.—Shaft position digitation is defined as the process of converting and expressing the instantaneous position of a shaft in digital form. The simplest method of shaft-position digitation is similar to the technique that has been described in connection with shaft-rotation digitation. In the shaft rotation method, where the total revolutions or a function of total revolutions is to be read out, a decade type counter is used in order to obtain relatively high readings. For position indication, only a relatively small number of positions is required. It is therefore possible to use only one counter wheel which contains as many digits as may be desired, each digit representing a definite rotary position of the shaft.

If the number of positions is very large, a decade type counter would be helpful. The use of seven counter wheels could theoretically produce extremely fine readings, with a resolution as fine as one second of arc. Two of the wheels could be used to produce the readings from 00 to 60 seconds; the next two to the left could read from 00 to 60 minutes; and the last three from 000 to 360 degrees.

Unfortunately, the similarities between this technique and the preceding one also reveal the limitations involved, since this method also provides only a readout or readin device.

Shaft-Position Digitation By Mechanical Switching.—A device that is more useful than the previous devices in at least one respect can be devised by replacing the counter with a mechanical switching arrangement. Either cam-operated sensitive switches or a multipurpose rotary switch can be used. With this method, the output is electrical, although the device is basically mechanical. If each switch or tap feeds separate lines, the various output signals will correspond to each separate shaft position. The signals could be used either as an input to some type of computing device, or to feed numbered output lamps.

A disadvantage of this device is the physical limitation associated with the number of positions that can be read out. Each additional position requires the addition of another sensitive switch, or the use of a larger rotary switch, plus another lamp. Although such a device might be practical for applications such as calling out sixteen main points of a compass, any greater number of points would require the use of either an additional coding device or an entirely different technique.

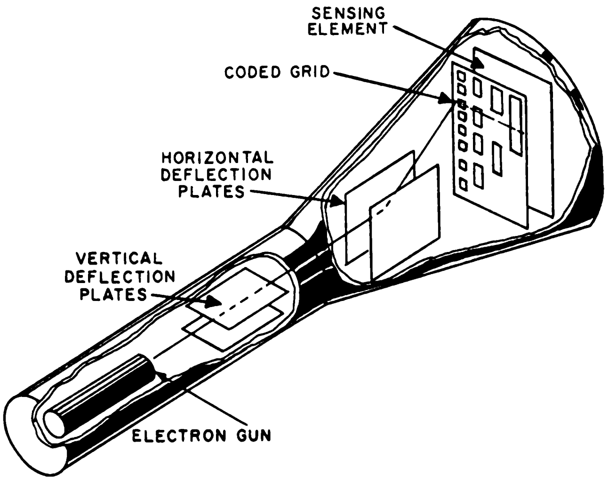
ELECTRICAL TECHNIQUES.—Electrical and mechanical techniques for analog-to-digital conversions are similar in some respects, but there are important differences. They both convert or "encode" analog inputs into digital outputs. Both types usually make use of a particular zero value setting as a reference point.

Two commonly used methods of performing analog-to-digital conversion by electrical means are the comparison method (explained in chapter 7) and the coding tube method explained here.

Coding Tube Method.—The coding tube method uses a specially designed cathode-ray tube (fig. 11-26). The special features of the tube are in the form of a grid, which contains rows of coded slots, and a special sensing element.

The coding tube method of performing analog-to-digital conversion consists of the following operations. The voltage that is to be converted is connected (after amplification) to the vertical deflection plates. A linear sawtooth sweep voltage is connected to the horizontal deflection plates. The connections to the vertical and horizontal deflection plates are not shown. The stream of electrons, which is emitted, focused, and accelerated by the electron gun, is positioned vertically on the grid so that it strikes a particular line of slots that correspond to the amplitude of the voltage to be converted.

The linear sawtooth voltage on the horizontal deflection plate causes the beam to be scanned



20.320(124)
Figure 11-26.—The cathode-ray tube.

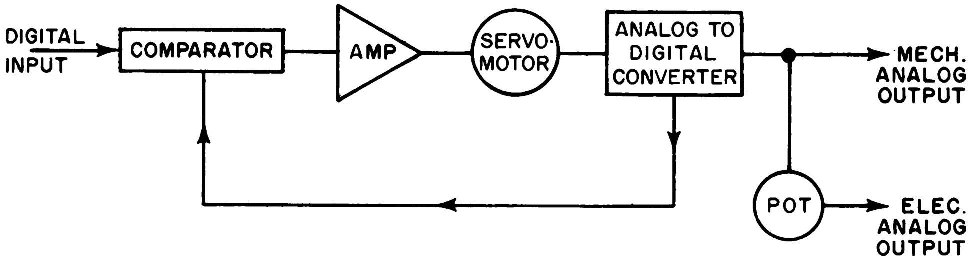


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Figure 11-27.—Block diagram of a mechanical digital-to-analog (D-A) converter.

across the line of slots. This action causes a coded image to be developed on the sensing element, which serves as the digital readout device.

High speed is the main advantage of the coding tube method of conversion. The disadvantages are that its accuracy is limited by the linearity of the scanning beam, and by the beam diameter or spot size. The greater the spot size, the less reliable is the result.

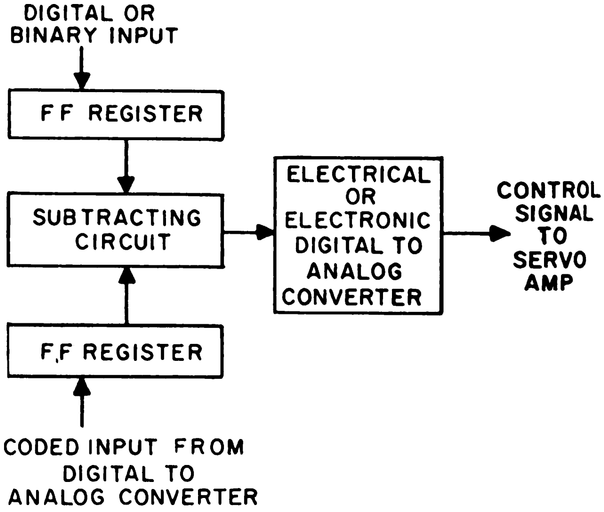
Digital-to-Analog Conversion

Digital-to-analog conversion, like analog-to-digital conversion, can be accomplished by both mechanical and electrical methods. The purpose of mechanical digital-to-analog conversions is to convert digital information into a mechanical movement or shaft position. Some of the basic principles involved in both methods are explained in the following paragraphs.

MECHANICAL TECHNIQUES.—Mechanical digital-to-analog conversion is almost always based upon feedback and comparison principles. A representative example of this action is illustrated in figure 11-27. The digital input is fed into a comparator which produces an input to a servoamplifier and servomotor combination. The servomotor is used to drive any of the many types of mechanical analog-to-digital converters. The digital output of the converter is fed back to the comparator, which operates as the error-detection circuit. As long as the digital output does not equal the input, an error signal will persist. This signal, in turn, causes the servomotor to continue to rotate until the error is reduced to zero.

The shaft or other mechanically driven device at the output of the analog-to-digital converter moves through a certain angle which is the analog representation of the digital input. If a transducer arrangement which uses a potentiometer for readout purposes is connected to the output shaft, an electrical signal will be produced which represents the same analog quantity.

One form of the comparator which will perform the desired error detection function is illustrated in figure 11-28. Using this arrangement the difference between the digital or binary input and the present actual instantaneous position of the servo shaft is constantly being converted into an analog signal which is applied to the servoamplifier. The flip-flop (FF) registers store their respective inputs. The subtracting circuit computes the difference and interprets this difference as the existing error. When the analog shaft position corresponds to the digital input


DIGITAL OR BINARY INPUT
F F REGISTER
SUBTRACTING CIRCUIT
ELECTRICAL OR ELECTRONIC DIGITAL TO ANALOG CONVERTER
CONTROL SIGNAL TO SERVO AMP
F.F REGISTER
CODED INPUT FROM DIGITAL TO ANALOG CONVERTER

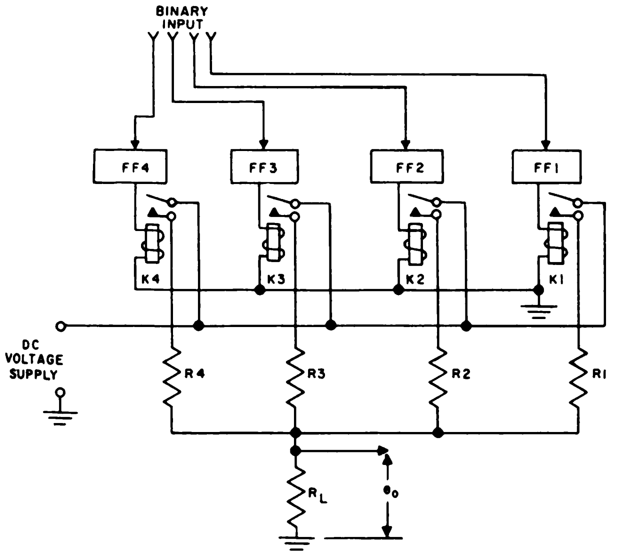
124.105

Figure 11-28.—Representative comparator, block diagram.

(as indicated by a zero difference in the subtracting circuit), the signal to the servoamplifier will be zero and no further shaft rotation will occur.

ELECTRICAL TECHNIQUES.—Many electrical digital-to-analog converters operate on the principle of voltage division using selective relays and a series-parallel network of precision resistors. One of the simplest circuit arrangements based on this principle is shown in figure 11-29.

The binary (digital) input is fed into the bank of flip-flops. The 1 bits in the word stored in the flip-flops cause their respective relays to energize, which results in the closing of the associated contacts. Each of the resistors R_1 through R_4 is a precision resistor, i.e., it has very low tolerances. Assuming that each of the parallel branches conducts a given current value when its associated circuit switch is closed, it follows that the value of current through R_L is a function of the number of branches which are placed in the conducting state. If high accuracy is to be maintained, R_L must be kept small in comparison with resistors R_1, R_2, R_3, and R_4, even when these resistors are all connected in parallel. Because R_L is necessarily of low value, the output voltage (e_O across R_L) is low compared to the value of the input voltage (usually in the order of one volt). When higher output voltage levels or higher power output are required, the output voltage, e_O, can be amplified. (See Basic Electronics, NP 10087-C.)



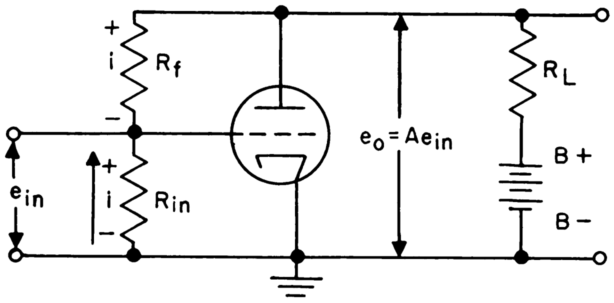
124.106
Figure 11-29.—Digital-to-analog conversion using selective relays and voltage dividers.

A similar method of performing digital-to-analog conversion involves the use of a series arrangement of resistors connected in a feedback loop of an operational amplifier circuit. In order to understand this method it is first necessary to discuss the basic principles of the operational amplifier, and also the principle of negative feedback amplifiers as they are used in operational amplifiers.

NEGATIVE FEEDBACK AMPLIFIER.—A schematic diagram of an amplifier which uses an electron tube and degenerative (negative) feedback is shown in figure 11-30. The characteristics of this amplifier are largely determined by the amount and type of feedback developed across R_f as will be shown presently.

In conventional amplifiers, any attempt to calculate the amount of amplifier voltage gain along a given parameter is complicated by changes in input and output impedances, polarity and amount of feedback, increases or decreases in frequency, and several other factors. It is shown in the following paragraphs that the voltage gain in a negative feedback amplifier is determined by the ratio of the feedback resistance (R_f —) to the grid resistance (R_{in}).

In the schematic diagram of figure 11-30, e_{in} represents the input signal voltage which, in this case, is developed across



124.107
Figure 11-30.—Schematic diagram of a negative feedback amplifier using an electron tube.

between grid and cathode of the tube. Simul- ously, an amplified voltage, which appears een grid and plate of the tube, is developed plate to ground (across R_L and the B supply e path and across R_f and R_{in} in the other). use of the inherent 180° triode phase shift een grid and plate, the feedback voltage de- ed across R_{in} is 180° out of phase with the signal voltage e_{in}. The opposing voltages ss this resistor produce the degenerative ack.

hat the gain A of the amplifier is equal to in can be shown as follows:

) $iR_{in} + iR_f = Ae_{in}$

2) $iR_{in} + iR_f = AiR_{in}$

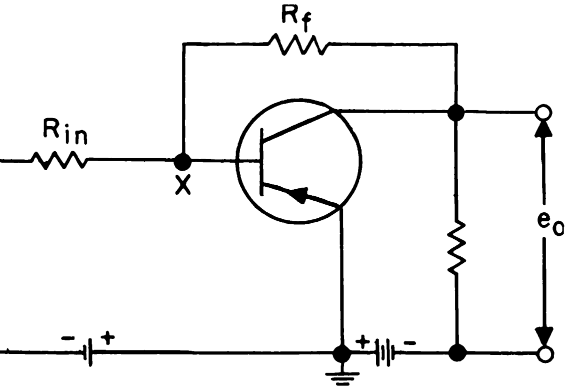
3) $R_{in} + R_f = AR_{in}$

4) $1 + \frac{R_f}{R_{in}} = A$

5) $\frac{R_f}{R_{in}} = A$

e A = stage gain and $e_{in} = iR_{in}$

use the ratio of R_f to R_{in} is usually the term 1 in equation (4) is ignored. he stage gain of the transistorized degen- ve amplifier in figure 11-31 is calculated he same way. The series connection of with respect to the emitter-base junction the input signal source permits the emitter- current to vary only slightly when rela- y large signal voltage changes occur at the input. Likewise, feedback current changes through R_{in} (which are very large compared to the forward emitter-base resistance) produce a large controlling effect on the amplifier output.



124.108
re 11-31.—Schematic diagram of a negative edback amplifier using a PNP transistor.

Also note that the large ohmic value of R_{in} with respect to the emitter base junction permits point X to maintain only a slight voltage value (negative) to ground.

Feedback and emitter base currents flowing at point X are relatively high. These factors make point X a point of low impedance, i.e.,

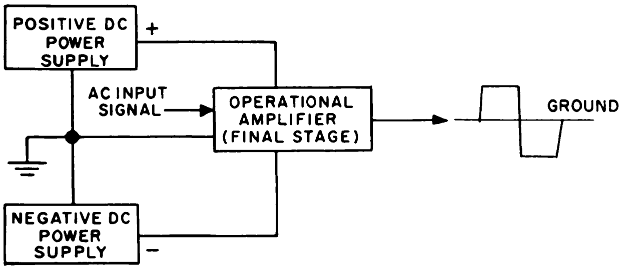
$$Z_x = \frac{e_x \text{ (low)}}{i_x \text{ (high)}}$$

Because of the large value of R_{in} with respect to the emitter-base resistance, the input current does not change appreciably over wide variations of the input signal amplitude. Thus the input source (as seen from point X) is, in effect, a constant current source. The input impedance is essentially the value of R_{in}, and point X is very near ground potential. The circuit will not produce a useful output if point X is maintained at zero volts, since this would mean that the amplifier input is zero. Rather, point X must be maintained at a slight voltage value to ground to permit accurate amplification. The type amplifier just described is frequently used in computers to multiply the d-c input by a constant (A), the stage gain.

OPERATIONAL AMPLIFIERS.—An operational amplifier is a very high gain direct-coupled feedback amplifier. It may consist of several stages, which, combined, produce output signals several million times the amplitude of the input.

An operational amplifier circuit is arranged so that the input signal is applied with respect to ground and the output signal is taken from a point on the final amplifier which is at zero volts d-c with respect to ground. The zero d-c level at the output is established by connecting the final amplifier stage across two power sources (fig. 11-32) whose outputs are of opposite polarity to ground. The output terminal is connected to that point on the amplifier which is at the zero volt d-c ground potential. It follows that a-c output signals alternate above and below the ground reference level.

The operation of an operational amplifier circuit (fig. 11-33) is as follows. Assume that an input signal, e_{in} (which tends to increase the d-c amplifier output current), is applied across the input terminals. The current output from the

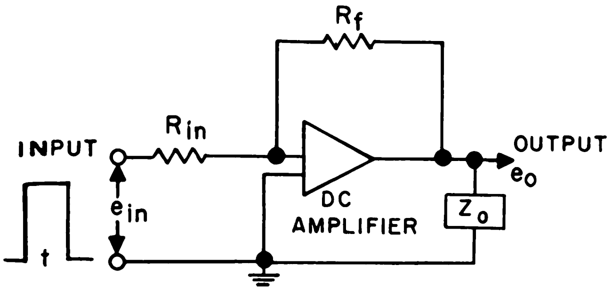


124.109
Figure 11-32.—Basic block diagram of operational amplifier showing methods used to obtain d-c ground at output.

circuit flows through R_f and the output impedance in parallel. Because R_f is (in general usage) several hundred times the size of R_{in}, and because the current through R_{in} is smaller than the current through R_f, it follows that the voltage across R_f will be many times the voltage across R_{in}. This ratio is a measure of the amplification.

Since the voltage across R_{in} is the input voltage (minus the neglibible drop across the emitter-base junction), the ratio of R_f/R_{in} represents the stage gain (A).

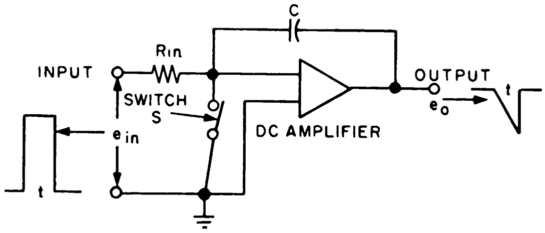
An operational amplifier can be used as a Miller sweep generator; or an integrator by replacing the feedback resistor Rf with a capacitor, C, as shown in figure 11-34. Switch, S, is added so that the integrating process can be started and stopped at a desired rate. In practice, switch S is replaced by an electronic switching device such as an electron tube or a transistor. The voltage amplifier is a high-gain high-impedance circuit.



124.110
Figure 11-33.—Operational amplifier using resistive feedback circuit.

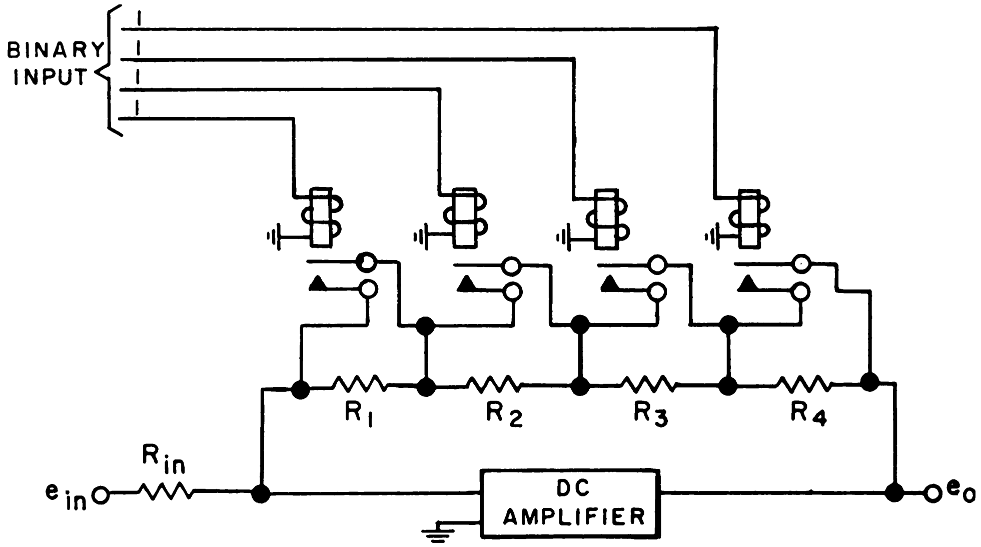
The degenerative feedback current through the capacitor, C, prevents the amplifier feedback voltage from changing instantaneously with E_{in}. The combined effects of the input voltage and the negative feedback maintain a constant charging current through C, which, in turn, produces a linear voltage change across this capacitor. The output voltage is proportioned to the integrated input voltage. The slope of the output waveform is dependent upon the time constant R_{in} C_{FB}. Where R_{in} = 1 megohm and C_{FB} = 1 microfarad the time constant is 1 and the slope is linear.

DIGITAL-TO-ANALOG CONVERSION USING THE SERIES RESISTOR METHOD.—The circuit in figure 11-35 contains a series array of resistors (R_1 through R_4, of selected sizes) in the feedback loop of an operational amplifier. Each resistor is bypassed by a pair of relay contacts which represent zero (or OFF) in the closed position and one, (or ON) in the open position. When all of the contacts are closed, there is zero resistance in the feedback path, and the amplifier will not produce a voltage gain. When a 1 binary input is applied across any or all of the relay solenoids, the associated contacts open (as shown) causing resistance to be added to the feedback loop. The amount of increase in the amplifier gain is in direct proportion to the amount of resistance placed in the feedback loop by the opening of the relay contacts. The voltage, e_o, therefore represents the analog value of a digital input.



124.111
Figure 11-34.—Operational amplifier using capacitive feedback circuit.

THE DIGILOG CIRCUIT.—A digilog circuit (sometimes called a decoder) is used to convert digital signals to analog voltages. In effect, it is a translator. It translates the language of digital devices ("1's" and "0's") into the language



124.112

Figure 11-35.—Digital-to-analog conversion using operational amplifier and a series array of feedback resistors.

of analog devices. These analog voltages are then used to position needles on meters, oscilloscopic sweeps, and/or dots on cathode-ray tubes, turn motor shafts, drive analog circuits, etc.

The digilog is composed of a bank of transistor switches and a resistive network known as a "ladder-adder." Figure 11-36 shows a block diagram of one transistor switch and the ladder-adder network. In an actual circuit where several digital inputs are received, a transistor switch is needed for each binary input digit. The transistor switches are opened and closed by the digital signal, allowing either a voltage or ground to be presented to the ladder-adder resistive network. The output of the ladder-adder is the required analog voltage.

DIGILOG TRANSISTOR SWITCH.—The purpose of the transistor switches is to supply a voltage to the ladder-adder as determined by the binary value of the digit which controls each switch. There are, of course, many transistor circuit configurations which may be used to accomplish the switching. Generally, the digilog switching circuit will be similar to that shown in figure 11-37. The circuit of figure 11-37 uses a positive reference voltage V_{Ref}, as indicated at the emitter of Q1. By replacing Q1 with an NPN transistor and Q2 with a PNP transistor and properly biasing the transistors, a negative reference voltage can be switched into the ladder-adder.

As stated earlier, a transistor switch is needed for each binary input digit. For example:

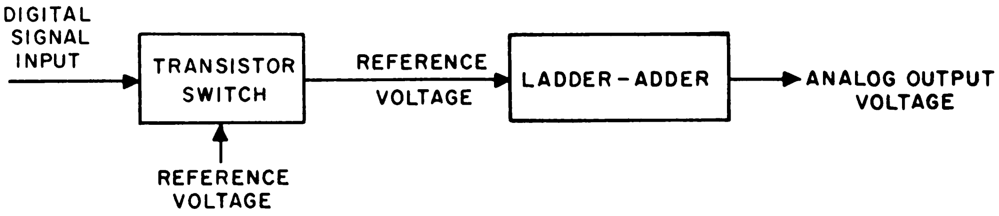


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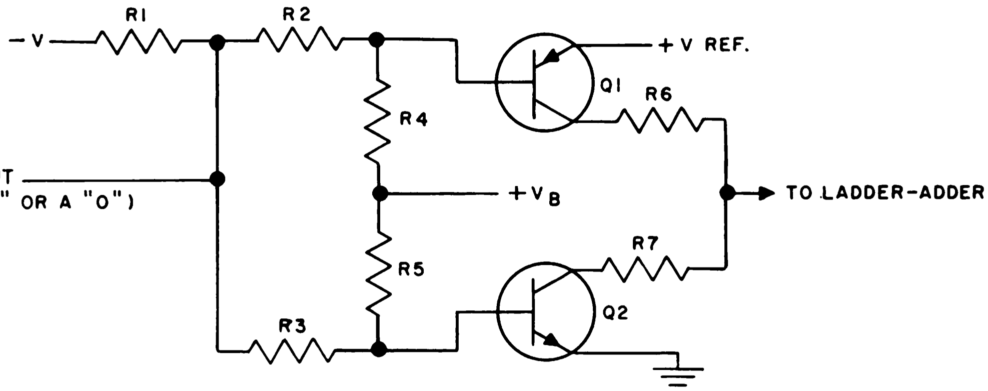
Figure 11-36.—Block diagram of digilog action.



124.114

Figure 11-37.—Digilog transistor switch.

A four digit word requires four transistor switches and a ten digit word requires ten transistor switches. In figure 11-37 it is assumed that the true (-V) or "1" state is represented at the input and that the false or "0" input state is represented as 0V. With a true (-V) at the digital input terminal, Q1 conducts heavily and Q2 is cut off. Hence, the + V_{Ref} is supplied to the ladder-adder via the low conducting resistance of Q1 in series with R6. When the input is false (0V), Q1 is cut off and Q2 conducts, applying ground to the ladder-adder via the low conducting resistance of Q2 in series with R7.

THE LADDER-ADDER RESISTIVE NETWORK.—For purposes of explanation, four transistor switches and the corresponding ladder-adder network are illustrated in figure 11-38.

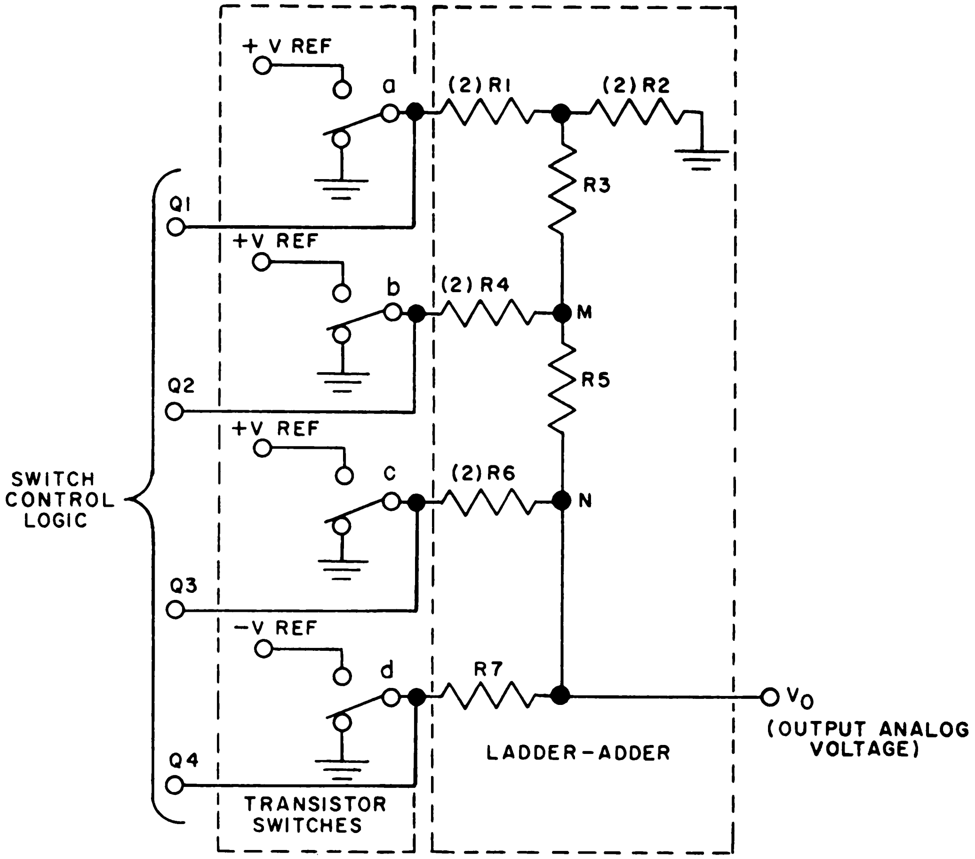
It is important to remember that in a practical application, the digilog can have as many transistor switches as desired and the associated ladder-adder network. A four switch digilog has 16 possible voltage levels as an output. This is so because the input can be either true or false (-V or 0) and there are four input switches. Hence, there are 2^4, or 16, possilbe input and output combinations. A ten switch digilog has 2^{10} or 1024 possible output voltage levels. The greater the number of switches in the digilog, the smaller the incremental difference in the output voltage levels, as will be shown later. For simplification, the transistor switches have been replaced by toggle switches.

Certain basic requirements must be met with regard to relative resistance values and supply voltages in order to produce satisfactory results from the ladder-adder network. These are as follows: Resistors R3 = R5 = R7 and R1 = R2 = R6 = 2R3. A + V_{Ref} and -V_{Ref} of equal absolute value must be used. To aid in understanding the digilog, the following values are assigned:

A. R3, R5, R7 = 5K ohms
B. R1, R2, R4, R6 = 10K ohms
C. +V_{REF} = +10 volts
D. -V_{REF} = -10 volts

Table 11-3 shows the possilbe input conditions to the digilog switches, the corresponding position of each switch (either ground or a reference voltage), and the analog output voltage. A positive reference voltage is utilized at switches a, b, and c, and a negative reference voltage for switch d, so that the output voltage (V_O) can swing from a maximum positive voltage value through zero volts to a maximum negative voltage. In practice though, the digilog can be constructed to vary between any two voltage levels desired.

A few of the output voltages produced at the ladder-adder output of figure 11-38 will be calculated using figure 11-39. When points a, b, and c are grounded and d is connected to the -10 volts reference, the circuit equivalent is as illustrated in figure 11-39A. Note that resistors R1 and R2 combine into a single 5K resistance in series with R3 (5K) to ground. The resistance from point M to ground is now



124.115

Figure 11-38.—A four-digit digilog.

5K, as illustrated in the equivalent circuit of figure 11-39B.

$$R_{eq1}\ (R3 + \frac{R_1 \times R_2}{R_1 + R_2})\ \text{is in parallel with R4}$$

to ground and the combination is in series with R5. Disregarding R6, these three resistors (R4, R5, and R_{eq1}) combine to form a new equivalent resistance to ground from point N (fig. 10-43B), which is 10K. This results in

$$R_{eq2}\ (R5 + \frac{R4 \times R_{eq1}}{R4 + R_{eq1}})$$

as shown in figure 11-39C.

Resistors R6 and R_{eq2} constitute a parallel combination which results in R_{eq3} (fig. 11-39D) from point N to ground of 5K. This represents the final equivalent of the circuit in figure 11-38 with points a, b, and c grounded and point d connected to a -10V supply. In figure 11-39D, V_O is -5V, which is the maximum negative voltage obtainable from the digilog in figure 11-38.

Now consider another condition which can exist in the circuit of figure 11-38. Leaving point d connected to the -10V reference and points a and b connected to ground, the V_O will be calculated when point c is connected to the +10V reference.

From the previous discussion the equivalent circuit will be as shown in figure 11-39E

Table 11-3.—Input and output levels for four-digit digilog

Possible Switch Controlling Input Conditions				Switch Position Due To Input Conditions				Analog Output Voltage
Q4	Q3	Q2	Q1	d	c	b	a	V_0 (volts)
0	0	0	0	gnd	gnd	gnd	gnd	0
0	0	0	1	gnd	gnd	gnd	+ 10v	+ 0.625
0	0	1	0	gnd	gnd	+ 10v	gnd	+ 1.250
0	0	1	1	gnd	gnd	+ 10v	+ 10v	+ 1.875
0	1	0	0	gnd	+ 10v	gnd	gnd	+ 2.500
0	1	0	1	gnd	+ 10v	gnd	+ 10v	+ 3.125
0	1	1	0	gnd	+ 10v	+ 10v	gnd	+ 3.750
0	1	1	1	gnd	+ 10v	+ 10v	+ 10v	+ 4.375
1	0	0	0	-10v	gnd	gnd	gnd	- 5.000
1	0	0	1	-10v	gnd	gnd	+ 10v	- 4.375
1	0	1	0	-10v	gnd	+ 10v	gnd	- 3.750
1	0	1	1	-10v	gnd	+ 10v	+ 10v	- 3.125
1	1	0	0	-10v	+ 10v	gnd	gnd	- 2.500
1	1	0	1	-10v	+ 10v	gnd	+ 10v	- 1.875
1	1	1	0	-10v	+ 10v	+ 10v	gnd	- 1.250
1	1	1	1	-10v	+ 10v	+ 10v	+ 10v	- 0.625

124.274

(batteries added for continuity). The output voltage is calculated using simultaneous equations. The current through R6 is arbitrarily referred to as i_1, the current through R_{eq2} is called i_2, and the current through R7 is $i_1 + i_2$ by Kirchhoff's law; the sum of the voltage drops around a closed circuit is equal to the source voltage. (The source voltage applied in a circuit is sometimes the combined voltage of two or more supplies.) Thus:

(1) $E_{R7} + E_{R6} = E_1 + E_2$

(2) $E_{R7} + E_{Req2} = E_2$

(3) $E_{R6} - E_{Req2} = E_1$

Substituting current x resistance in equation (1)

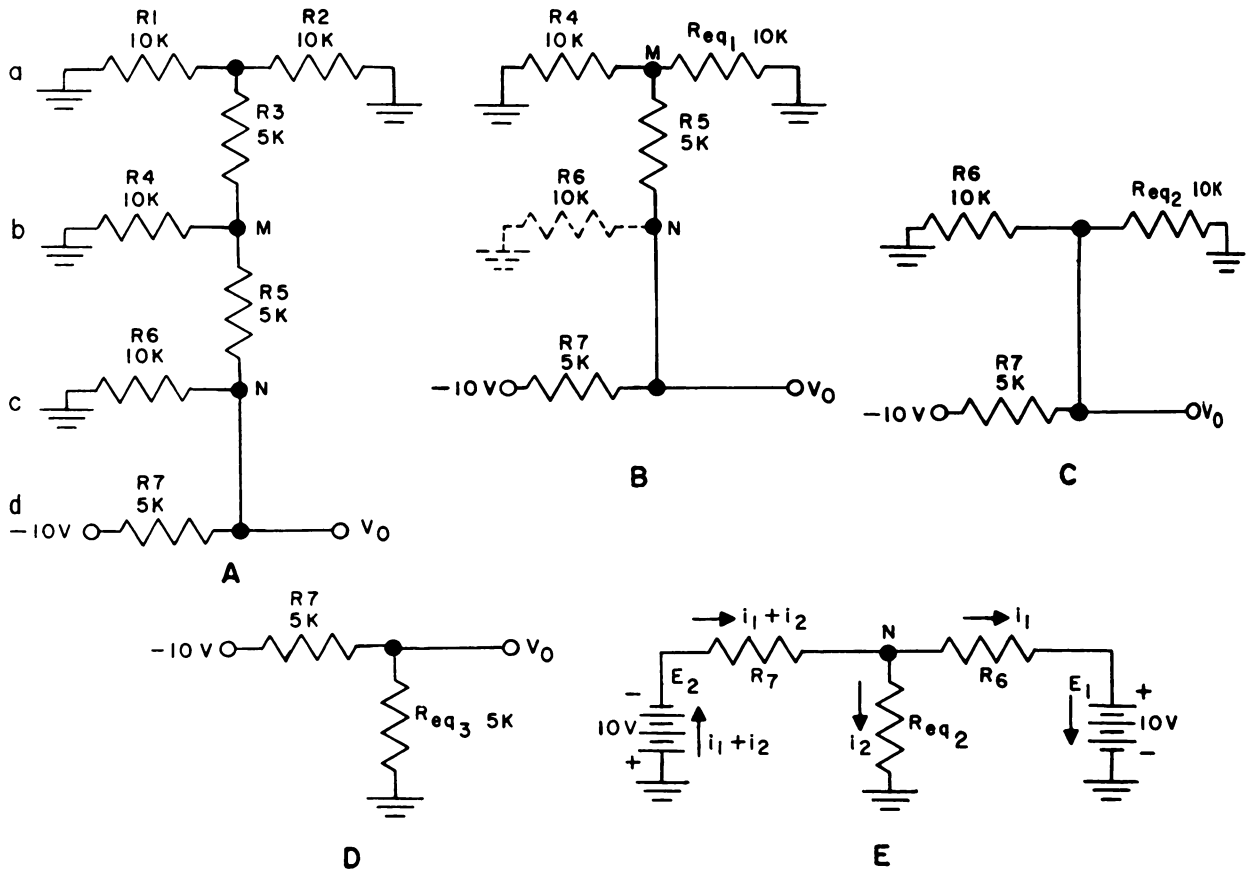
$$5K\,(i_1 + i_2) + 10K\,(i_1) = 20$$

Substituting current x resistance in equation (2)

$$5K\,(i_1 + i_2) + 10k\,(i_2) = 10$$

Substituting current x resistance in equation (3)

$10K\,(i_1) - 10K\,(i_2) = 10$ (Note that the two voltage supplies tend to produce currents through



124.116

Figure 11-39.—Analysis of ladder-adder circuits.

R_{eq2} in opposite directions. Thus, the voltage developed across R_{eq2} is the resultant voltage established by the opposing supplies.)

Simplifying the equations

$$5K\,(i_1 + i_2) + 10K\,(i_1) = 20$$

$$5K(i_1) + 5K(i_2) + 10K(i_1) = 20$$

(a) $15K(i_1) + 5K(i_2) = 20$

$$5K(i_1 + i_2) + 10K\,(i_2) = 10$$

$$5K(i_1) + 5K(i_2) + 10K(i_2) = 10$$

(b) $5K(i_1) + 15K(i_2) = 10$

From equations (a) and (b); where equation (b) is multiplied by 3.

$$\cancel{15K(i_1)} + 5K(i_2) = 20$$

$$\underline{\cancel{15K(i_1)} + 45K(i_2) = 30}$$

$$-40K(i_2) = -10$$

$$i_2 = \frac{-10}{-40K}$$

$$i_2 = .00025 \text{ ampere}$$

Solving for current (i_1)

$$15K(i_1) + 5K(1/4\text{mA}) = 20V$$

$$15K(i_1) = 20V - 1.25V$$

$$i_1 = \frac{18.75V}{15K}$$

$$i_1 = .00125 \text{ ampere}$$

Using Ohms law and substituting in equation 2)

$$E_{R7} + E_{Req2} = E_2$$

$$5K(i_1 + i_2\} + 10K(i_2) = 10V$$

$$5x10^3 (.00125 + .00025) + 10x10^3 (.00025) = 10V$$

$$5 x10^3 (.00150) \qquad + 10 x 10^3 (.00025) = 10V$$

$$5x10^3 \ (150x10^{-5}) \ + 10x10^3 \ (25x10^{-5}) \ = 10V$$

$$750V \ x \ 10^{-2} + 250V \ x \ 10^{-2} = 10V$$

$$7.5V + 2.5V = 10V$$

$$7.5V - 10V = -2.5V$$

Thus, V_O = -2.5V when point d (fig. 11-38) is connected to the -10V reference, points a and b are grounded, and point c is connected to the +10V reference.

Leaving point d (fig. 11-39) connected to the -10V reference, c to the +10V reference, and a to ground, the V_O will be -1.25V when point b is connected to the +10V reference (calculation not shown). With all points (a, b, c, and d) connected to reference voltages, the V_O is -.625V, which is the minimum negative voltage output available. If all inputs to the ladder-adder are at ground, V_O is zero volts. Minimum positive voltage output is obtained when point a is connected to the +10 volt reference and points b, c, and d are grounded. Maximum positive output voltage is obtained when points a, b, and c are connected to the +10V reference, and point d is grounded.

LINE DRIVERS AND INPUT AMPLIFIERS

In those cases where data is transmitted between equipment in digital form (electrical pulses), special circuits are used as line drivers and input amplifiers. The line driver circuits provide the signal power required to trigger the input amplifiers of the receiving equipment.

The input amplifiers receive their inputs from the line drivers of transmitting equipment. In many instances, the input amplifier must be gated by a gate signal before data is entered into the receiving equipment. In this manner the flow of data between equipment is controlled.

CHAPTER 12

GENERAL PURPOSE TEST EQUIPMENT

INTRODUCTION

An understanding of the operation of components and circuits as presented in the preceding chapters is necessary to maintain fire control equipment. In addition, you must possess many practical skills and must know special procedures for testing and servicing electrical and electronic equipment. Trouble-free equipment, to a large extent, depends on the quality and type of workmanship used in maintaining it.

In this chapter we will discuss some of the general purpose electrical and electronic test equipment used by missile fire control technicians. The discussion will include comments on some of the methods and techniques used in testing radar RF emissions.

The theory of general purpose test equipment is covered in the Basic Electricity and the Basic Electronics courses. Therefore, our effort will be to supplement that information.

You will find that there are various equipment units that perform the same function. The use and operation of a particular type of test equipment, however, is basically the same for all models.

Your study of this chapter will include the following:

1. General purpose test equipment
2. Test methods and practices
3. Precautions required for the proper use of test equipment

ELECTRICAL METERS

A thorough understanding of the construction, operation, and limitations of electrical measuring instruments, coupled with the theory of circuit operation, is most essential in servicing and maintaining electrical equipment. Remember that the best and most expensive measuring instrument is of NO use to the man who does not know what he is measuring or what the readings indicate.

The three types of meters that you will most frequently encounter are ammeter, ohmmeter, and voltmeter. It is well to pay special attention to each application in the following discussion.

The AMMETER is used to measure current. It must always be placed in series with the circuit to be measured. The ammeter consists of a basic meter movement and a combination of shunt resistors in parallel with it. A multiposition switch or a series of pin jacks is used to allow the use of various sizes of shunt resistors to give different current ranges. When using an ammeter, always have the meter on the highest range before connecting it to a circuit.

The OHMMETER is widely used by missile fire control technicians in making resistance measurements and continuity checks. You will find wide use for this instrument in checking cables and locating malfunctioning components in electrical circuits. The ohmmeter consists of a basic meter movement connected as an ammeter, a voltage source, and one or more resistors used to adjust the current through the meter movement. The meter must be adjusted for "zero resistance" prior to making resistance measurements. Care must also be exercised not to use an ohmmeter on an energized circuit.

The VOLTMETER utilizes the basic meter movement by placing a high resistance in series with it. The value of this series resistance is determined by the current necessary for full-scale deflection of the meter and the voltage being measured. Because the current is directly proportional to the voltage applied, the scale can be calibrated directly in volts for a fixed series resistance.

The sensitivity of voltmeters is given in ohms per volt, and may be determined by dividing the resistance of the meter plus the series resistance by the full-scale reading in volts.

This is the same as saying that the sensitivity s equal to the reciprocal of the current (in amperes). Thus, the sensitivity of a 100-microampere movement is the reciprocal of 0.0001 ampere or 10,000 ohms per volt. The sensitivity of the meter depends on the strength of the permanent magnet field and the weight of the moving coil.

The sensitivity of a voltmeter is an identification of how accurately it measures voltages n a circuit. In many cases, a sensitivity of 1,000 ohms per volt is satisfactory; however, f the circuit in which the voltage is being measured has high resistance, a greater sensitivity is required for accuracy. The higher the sensitivity rating, the higher the resistance in the meter branch of the circuit, and the less the possibility of the meter shunting the circuit. If a meter of ow ohms per volt is used to measure the voltage in a high resistance circuit, the meter will shunt the load being measured and result in an inaccurate reading. Thus, the higher the sensitivity, the more accurate is the reading.

Like the ammeter and ohmmeter, the voltmeter normally utilizes several resistors with a switching arrangement to permit multirange operation. The importance of setting the selector switch for maximum voltage range before connecting it to an energized circuit cannot be overemphasized.

In the selection of an a-c voltmeter, the frequency and waveform of the voltage being measured must be taken into consideration. Although some a-c voltmeters react to the peak value and others to the average (of one alternation) value, most a-c voltmeters are calibrated to indicate effective (RMS) values of voltage. RMS is explained in *Basic Electricity*, NavPers 10086-B.)

MULTIMETERS

Multimeters capable of measuring a-c voltages utilize conventional d-c meter movements and metallic oxide rectifiers to change the a-c to d-c. Most multimeters have an accuracy of 2 to per cent at low frequencies. However, the shunt capacity of the metallic oxide rectifiers affects the accuracy of the multimeter as the frequency of the voltage being measured increases. When the frequency is above the audio range, the voltage reading is no longer accurate. Where accuracy at the higher frequencies is desired, an electronic multimeter or an a-c vacuum tube voltmeter should be used.

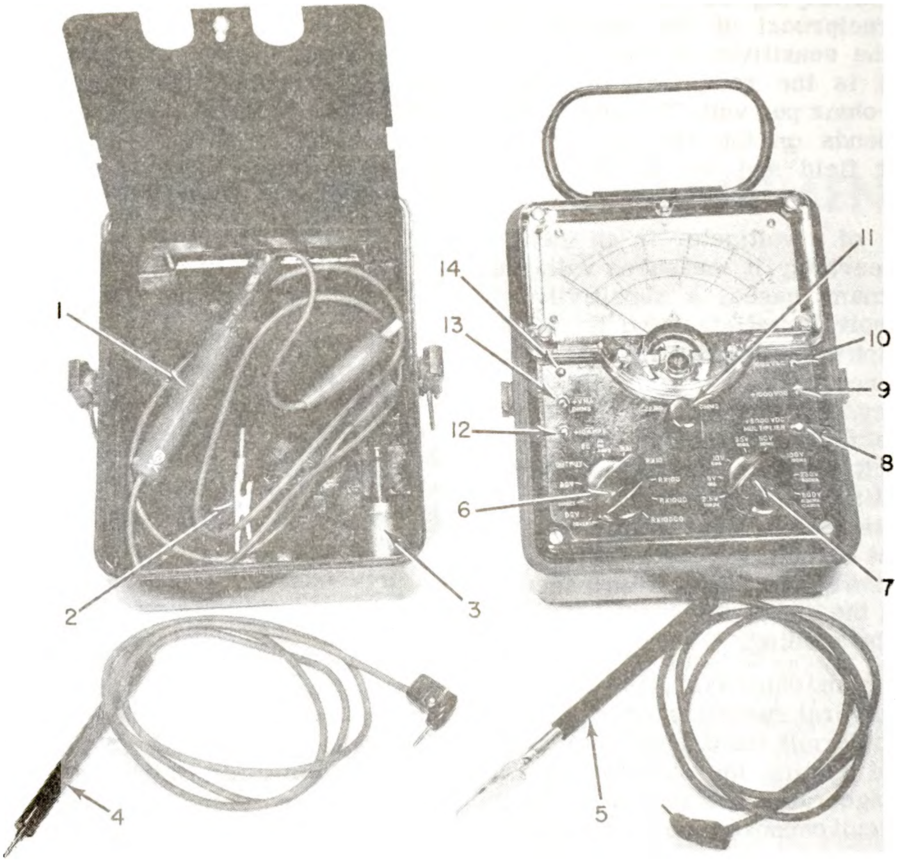
MULTIMETER AN/PSM-4

The multimeter AN/PSM-4C (fig. 12-1) is designed to permit the technician to make measurements of voltage, resistance, and current with a completely self-contained portable instrument. It can measure either a-c or d-c voltage, d-c resistance, or direct current in a wide range of values. This capability covers the basic requirements for a portable tester of this type. All leads and accessories are stored in a compartment built into the cover, which should remain with the instrument at all times. The cover forms a watertight seal when clamped over the face of the meter. While the instrument is in use, the cover clamps over the back of the meter keeping the accessory compartment convenient to the operator. Batteries used with the meter are: one BA-30 (1.5 volts) and one BA-261/U (22.5 volts).

In the accessory compartment there is a pair of standard test leads (one red and one black) which are used for most applications of the instrument. These leads have elbow probes on one end to connect the lead into the circuit jacks on the instrument. They have probe tips on the other end, which have threaded shoulders to accept the alligator clips which are screwed on. These parts are used to make all measurements, except d-c voltage over 1,000 volts.

For measuring d-c voltages over 1,000 volts, a special high voltage probe is provided, and is used in conjunction with the standard black lead. One end of the lead has a threaded tip which screws on a post in the face of the meter (labeled 5,000 VDC MULTIPLIER). The other end of the lead has a high-voltage multiplier assembly made of red plastic with a clear plastic end and terminates in a crocodile clip at the end of a short piece of flexible wire. The clear plastic end allows the operator to observe the glow of a neon lamp when there is high voltage present. This is a warning to the operator that there is high voltage present at the clip and that he should not touch it. The neon lamp is in series with a 100-megohm resistor within the housing. When a high voltage is being measured, the current passes through the lamp making it glow, through the resistor, and through the armature of the meter.

There are three controls on the face of the meter. One is a 10-position rotary switch in the lower left-hand corner which is used as a function switch. Five of the positions on this switch are used to set up different resistance scales. Two of the positions are for selection



1. High voltage probe.
2. Alligator clips.
3. Telephone plug.
4. Standard test lead (red).
5. Standard test lead (black).
6. Function switch, S101.
7. Current and voltage range selector, S102.
8. +5,000 VDC multiplier.
9. +1,000 VDC (red lead).
10. 1,000 VAC (red lead).
11. Zero ohms.
12. +10 amps (red lead).
13. +Volts/MA/ohms (red lead).
14. Common (black lead).

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Figure 12-1.—Multimeter AN/PSM-4C.

of d-c voltage measurement (direct and reverse). The normal position of the switch is in the DIRECT position. if a negative voltage is to be measured, the switch is moved to the REVERSE position. (NOTE: Never switch leads to read a reverse or negative voltage.) One position of the switch is marked ACV; in this position the meter may be used to read a-c voltage. A rectifier in the instrument changes the a-c voltage to an equivalent d-c value which is applied to the meter. One position is marked OUTPUT; in this position the a-c portion of mixed a-c and d-c voltage may be read. The last position of the switch is used when measuring direct current and is marked DC with three ranges (μA, MA, AMPS) indicated to the right of the letters DC In the lower right-hand corner is an eight-position switch used to select current and voltage ranges. Near the center of the meter is a control marked ZERO OHMS. This control, which is a continuously variable adjustment, is used to zero the meter thus compensating for battery aging in the ohmmeter circuits. This control is adjusted until the meter indicates full-scale deflection (indicating zero ohms) when the function switch is set at one of the resistance range positions and the meter probes are shorted together. To prevent erroneous readings when switching to a different position, a check of the meter zero indication is always necessary.

The Multimeter AN/PSM-4C is designed to nake the following electrical measurements:

1. Measure direct current up to 10 amperes
2. Measure resistances up to 300 megohms
3. Measure d-c voltages up to 5,000 volts
4. Measure a-c voltages up to 1,000 volts
5. Measure output voltages up to 500 volts

Input impedance for measuring d-c voltages s 20,000 ohms per volt and is accurate to vithin 3 per cent of full-scale (4 per cent for he 5,000 VDC scale). When measuring a-c oltages, the input impedance is 1,000 ohms per olt and is accurate to within 5 per cent of full cale.

The following discussion and the associated lock diagrams treat the general circuit within he instrument part of the multimeter as it is rranged when used to measure voltage, current, r resistance.

DC Voltmeter Circuits

The block diagram of the circuit in Multineter AN/PSM-4C which is used for measuring l-c voltages is shown in figure 12-2A. The ircuit is selected with function switch S101, n either its DIRECT or REVERSE DCV position fig. 12-1). For voltages up through 500 volts, . range is selected with range switch S-102 only one position shown in figure 12-2A). For he 1000 volt range, the red test lead connects nto the special 1000 VDC jack (fig. 12-1), and the ange switch is not in the circuit. For the 5000-olt range the high voltage probe (not shown) onnects the special 5000 VDC jack, and places s resistance in series with the meter movement. 'or any range, the total resistance in series ith it will regulate the meter current to provide proportional current to indicate the amount of oltage in the circuit.

AC and Output Voltage Circuits

The circuits which measure a-c and output oltages (fig. 12-2B) are selected with the ACV nd OUTPUT positions of function switch S-101. or voltages up through 500 volts, a range is elected with range switch S-102. For the 1000 olt range, the red test lead connects into the pecial 1000 VAC jack, and the range switch, -102, is not in the circuit. The a-c voltage npressed across the circuit between the red d black test lead sends current through the esistance of the circuit in both directions, but e rectifier allows only one direction of current ow through the meter movement. The meter is alibrated to indicate the RMS value of the a-c oltage applied to the instrument circuit.

DC Current Circuits

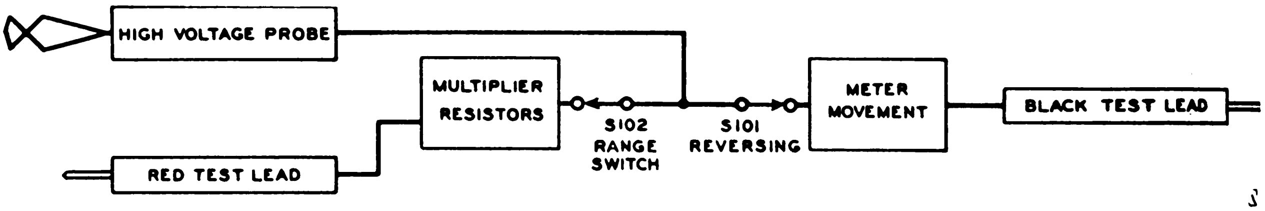
The circuit which measures d-c currents (fig. 12-2C) is selected with the DC μA MA AMPS position of function switch S-101. For currents up to 1000 milliamperes, the range is selected with range switch S-102. For the 10 ampere range, the red test lead connects into the special 10 AMPS jack, and range switch S-102 is not in the circuit. Each range provides a parallel shunt resistance for the meter movement, and the circuit current divides between these two parallel paths. The proportional part which passes through the meter movement indicates the total circuit current.

Ohmmeter Circuits

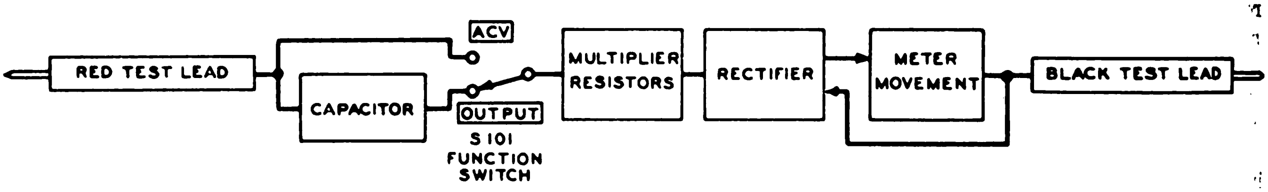
The ohmmeter circuit (fig. 12-2D) and its ranges are selected with function switch S101. Its positions are Rx1, Rx10, Rx100, Rx1000, and Rx10000. An internal battery furnishes the power for all resistance measurements. For each range, the circuit is arranged so the meter will indicate zero ohms and full scale deflection whenever the red test lead and the black test lead are shorted together. When you connect a resistance between the test leads, this resistance will be in series with the instrument circuit, and less current will flow through the meter movement. The amount of reduced meter deflection indicates how much resistance is between the test leads.

Application

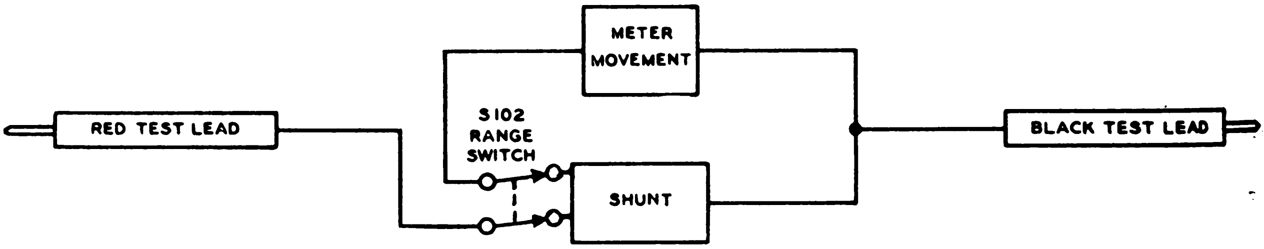
Function switch S-101 (fig. 12-1) located in the lower left-hand corner of the front panel, selects the type of circuit for which the instrument is connected. There are two positions for d-c volts: DIRECT AND REVERSE. The normal position is DIRECT. When using the meter to make a d-c voltage measurement and a connection is made which causes the meter to read backwards (deflection of the pointer to the left), set switch S-101 to REVERSE and the pointer will be deflected up-scale. Set switch S-101 at ACV to read alternating current voltages. A rectifier within the instrument will change the a-c voltage to an equivalent d-c value and apply this to the meter. The instrument will indicate the RMS value of the applied voltage. Set switch S-101 at OUTPUT to read the a-c portion of mixed a-c and d-c voltages. Set switch S-101 at DC μA MA AMPS to read direct current. Set switch S-101 at Rx1, Rx10, Rx100, Rx1000, or Rx10000 to read resistance. Switch S-101 also serves as a range switch for resistance measurements.



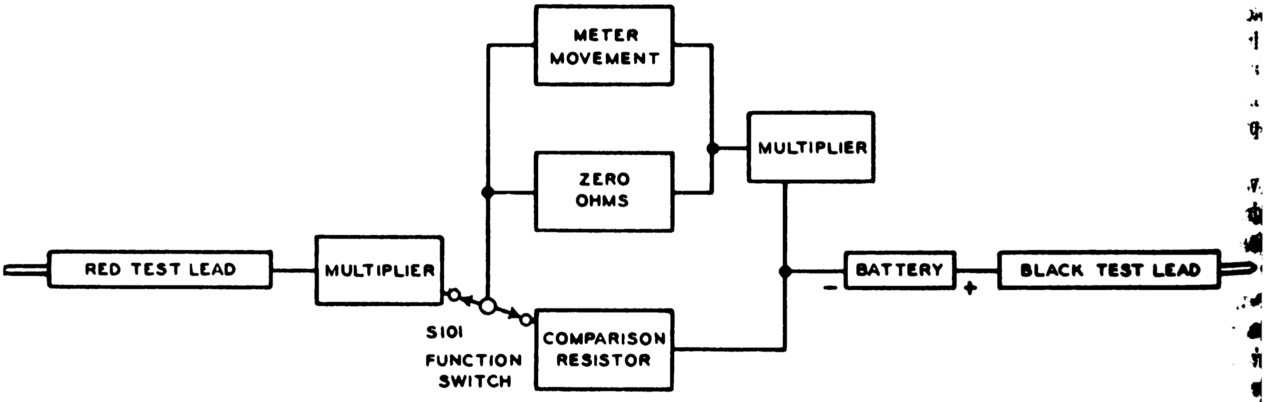
A. FUNCTIONAL BLOCK DIAGRAM OF DC VOLTAGE CIRCUITS



B. FUNCTIONAL BLOCK DIAGRAM OF AC AND OUTPUT VOLTAGE CIRCUITS



C. FUNCTIONAL BLOCK DIAGRAM OF DC CURRENT CIRCUITS



D. FUNCTIONAL BLOCK DIAGRAM OF OHMMETER CIRCUITS

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Figure 12-2.—Functional block diagram of AN/PSM-4C.

Range Switch S-102

This eight-position range switch located in the lower right corner of the front panel permits the selection of voltage and current ranges. The full scale value for each range switch position is marked on the front panel.

Zero Ohms Control

The ZERO OHMS control is located near the center of the front panel. Each time the function switch S-101 is placed in a position to read resistance, short the test leads together and rotate the ZERO OHMS control knob to make the pointer read full scale, or zero ohms. If you cannot bring the pointer to full scale, replace the battery in the rear of the case.

Under normal conditions, no routine service inspection is necessary beyond visual examination at established inspection periods. If the instrument is to be stored for periods of six months or longer, the batteries must be removed o prevent corrosion. The periodic inspection should include removal of the battery case cover o facilitate inspection of battery connections. f the instrument is used under extreme temperature conditions, a visual inspection of all parts should be made at least once a month. No periodic maintenance is required except for inspection, est, and replacement of batteries.

ELECTRONIC METERS

Electronic meters are used primarily for he same purposes as are the nonelectronic meters. Some characteristics of their operation, however, give them definite advantages. In the electronic multimeter, the current and resistance measuring circuits function in a manner identical o the corresponding nonelectronic measuring nstruments. The measurement of voltage, however, involves the use of an amplifier, which n turn requires that the meter be calibrated rior to use.

Proper calibration and use of the instruments ary slightly according to model. Details are included in the Operation Instruction Manual for ach model.

The ordinary voltmeter has several disadantages that make it practically useless for measuring voltages in high-impedance circuits. For example, suppose that the plate voltage of pentode amplifier is to be measured. (See g. 12-3.) When the meter is connected between he plate and cathode of the electron tube, the meter resistance, R_m, is placed in parallel with he effective plate resistance, R_{eff}, thereby lowering the effective plate resistance. The effective plate resistance is in series with the plate load resistor, R_L, and this series circuit appears across the supply voltage, E_{bb}, as a voltage divider. Since the overall resistance is lowered, it follows that current through R_L will also increase, the voltage drop across R_L will also increase, and the voltage drop across R_{eff} will decrease. The result is an incorrect indication of plate voltage, and is called loading effect.

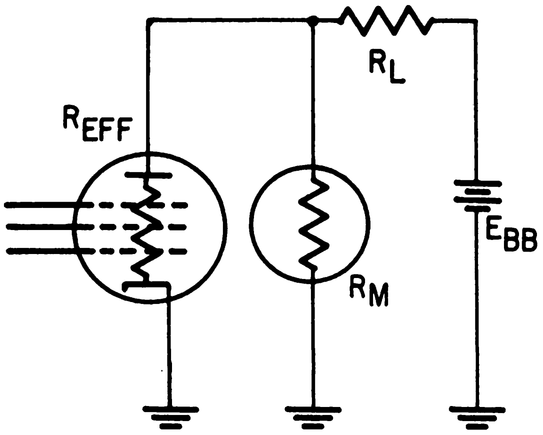

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Figure 12-3.—Loading effect created by meter resistance.

Calculation of Loading Effects

Before the voltmeter is connected, the plate current is determined by the effective resistance of the plate circuit, the plate load resistor, and the plate voltage. If the tube has an effective resistance of 100,000 ohms, a plate load resistance of 100,000 ohms, and the plate power supply is constant at 200 volts, then the plate current is

$$\frac{200 \text{ v}}{200{,}000\ \Omega}$$

or 0.001 ampere. The plate voltage (plate to cathode) is 0.001 x 100,000, or 100 volts.

Assume that the voltmeter used to measure the plate voltage of the tube has a sensitivity of 1,000 ohms per volt and that the selected meter range is from 0 to 250 volts. The meter will then have a resistance of 250,000 ohms. This resistance in parallel with the tube resistance of 100,000 ohms produces an effective resistance of 71,400 ohms in series with the plate load resistor. The total resistance across the plate voltage supply is therefore 171,400 ohms instead of the 200,000 ohms before the meter was applied, and the current through the plate load resistor is

$$\frac{200\ \text{v}}{171{,}400\ \Omega}$$

or 0.00117 ampere. Across the plate load resistor the voltage drop is 0.00117 x 100,000, or 117 volts, and the plate-to-cathode voltage on the tube is 200 - 117, or 83 volts when the meter is connected, thus causing an error of 17 volts. The lower the sensitivity of the meter, the greater the error will be; in this example, the error of 17 volts when the reading should be 100 volts is a 17-per cent error.

A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 per cent. However, in circuits where very high impedances are encountered, such as in grid circuits of electron tubes, even a meter of 20,000 ohms per volt sensitivity would impose too much of a load on the circuit.

VTVM Advantages

Another limitation of the alternating current, rectifier type voltmeter is the shunting effect at high frequencies of the relatively large capacitance of the meter's rectifier. This shunting effect may be eliminated by replacing the usual metallic oxide rectifier with a diode electron tube; the output of the diode is applied to the grid of an amplifier in which the plate circuit contains the d-c meter. Such a device is called an electron tube voltmeter or a vacuum tube voltmeter, usually abbreviated VTVM. Voltages at frequencies up to 500 megahertz, and sometimes even higher, can be measured accurately with this type of meter. The frequency limitation is determined by the model of VTVM.

The input impedance of a VTVM is large, and therefore the current drawn from the circuit whose voltage is being measured is small and in most cases negligible. The main reason for using a vacuum tube voltmeter is to overcome the loading effect by taking advantage of the VTVM's extremely high input impedance. A VTVM that is used extensively for electronics maintenance is contained in the AN/USM-116 Multimeter.

Vacuum Tube Voltmeter AN/USM-116

Multimeter AN/USM-116 is a portable, combination electronic instrument used for general servicing of electronic equipment. It is designed for use where precise voltage, current, and resistance measurements are required. It provides a direct reading of values on a single indicating meter mounted on the control panel (fig. 12-4). A high input-impedance permits voltage measurements to be made with only a small percentage of loading on the circuit under test. The multimeter can measure the following: Alternating current voltages and radiofrequency voltages which are indicated in RMS values; (actual deflection is proportional to the rectified peak value) a-c volts, d-c current, and resistance. The specific ranges for each of these functions are as follows:

1. a-c volts: 0.01 to 300 in RMS values
2. d-c volts: 0.02 to 1,000
3. d-c current: 20 microamperes to 1,000 milliamperes
4. Resistance: 0.2 ohm to 1,000 megohms

To understand the principles upon which the operation of Multimeter AN/USM-116 is based, refer to figure 12-5 while reading the following explanation.

The multimeter can measure a-c and d voltages as well as resistance and curren When measuring a-c voltages, the signal i first rectified by the diode in the probe. Th signal must be rectified because the mete circuit is sensitive only to d-c voltages. Whe d-c voltages are measured, the a-c probe con taining the diode rectifier is not needed.

The d-c or a-c voltage to be measured is applied across a voltage-divider network so th the total input impedance of the multimete remains constant when the position of ran switch S2 is changed for various levels o input voltage.

The meter is connected across a balanc bridge network. With no input, the bridge circu is balanced and the meter reads zero. Wh the bridge is unbalanced by an input voltage, the meter pointer is deflected up-scale. Switc S2 is used to connect the necessary resistan into the circuit for each range. The resistan across the voltage-divider networks reduces t input signal to a level suitable for applicatio to the bridge. There are three voltage-divid networks, one for each function.

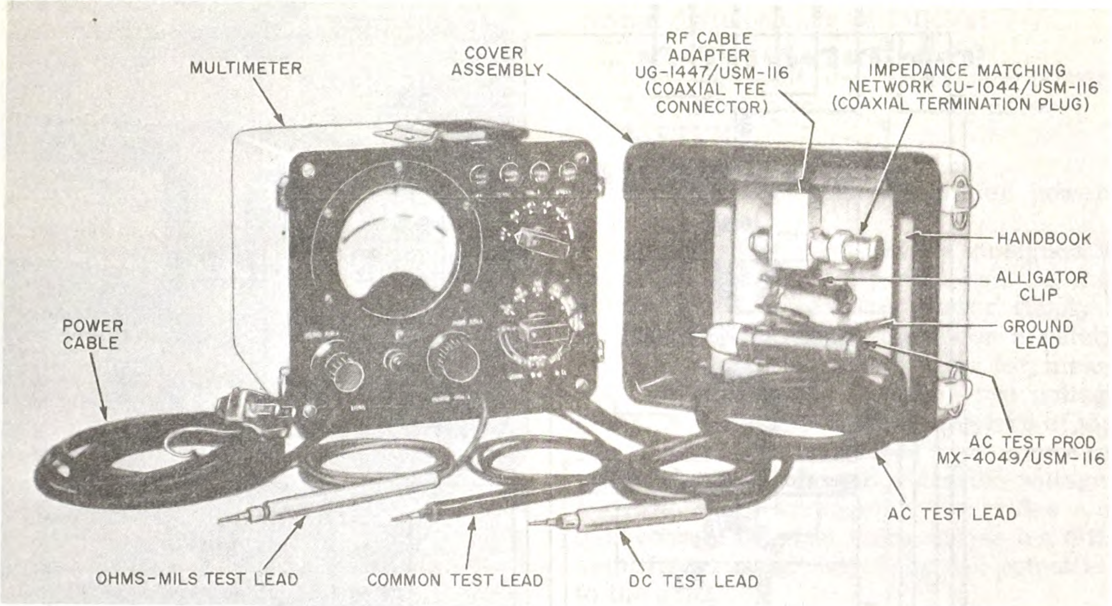
MULTIMETER
COVER ASSEMBLY
RF CABLE ADAPTER UG-1447/USM-116 (COAXIAL TEE CONNECTOR)
IMPEDANCE MATCHING NETWORK CU-1044/USM-116 (COAXIAL TERMINATION PLUG)
HANDBOOK
ALLIGATOR CLIP
GROUND LEAD
POWER CABLE
AC TEST PROD MX-4049/USM-116
AC TEST LEAD
OHMS-MILS TEST LEAD
COMMON TEST LEAD
DC TEST LEAD

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Figure 12-4.—Electronic Multimeter AN/USM-116.

The ohmmeter section also utilizes the bridge
ircuit. When an unknown resistance is placed
etween the OHMS-MILS lead and the COM
ead, the bias voltage on V2 decreases in pro-
ortion to the unknown resistance. The value of
e unknown resistance determines the degree to
hich the bridge is unbalanced and hence the
agnitude of the meter pointer deflection. No
attery supply is required for the ohmmeter cir-
uitry.

The milliammeter function does not make use
the bridge circuit. The range switch S2
onnects various shunts across the meter to
crease the range of current measurement.

A voltage regulator V5 tends to maintain the
+ supply voltage to tubes V2 and V3 at a con-
ant value despite changes in line voltage.

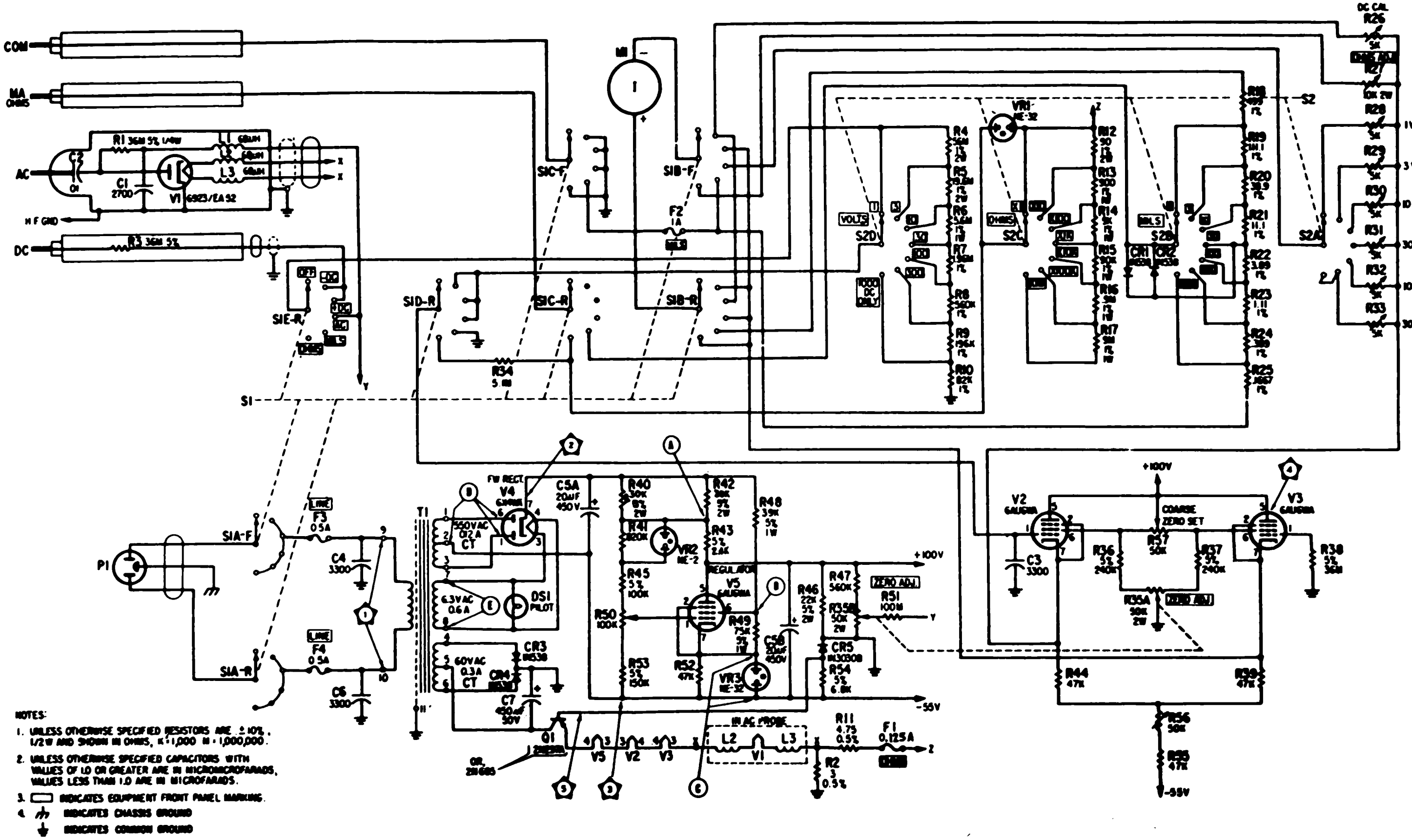
ifferential Voltmeter

The differential voltmeter is a reliable pre-
sion item of test equipment. Its general function
to compare an unknown voltage with an internal
ference voltage, and to indicate the difference
their values. The differential voltmeter in
ost common use in Navy applications is the
3D/AG (fig. 12-6), manufactured by the John
uke Co.

The 803D/AG is usable as an electronic voltmeter, as a precision potentiometer, and as a megohmmeter. It can also be used to measure the excursions of a voltage about a reference value. Ease of operation, inherent protection from any accidental overload, and high reliability of readings are additional advantages of the instrument. It is accurate enough for precision work in calibration laboratories, yet rugged enough for general shop use.

The heart of the unit is a precision 500-volt d-c reference power supply. This 500 volts can be precisely divided into increments as small as 10 microvolts by means of five voltage dials. Unknown a-c or d-c voltages are matched against the precise internal voltage until no deflection occurs on the panel meter. The unknown voltage is then simply read from the voltage dials. In the highest null sensitivity range, a potential difference between unknown and reference voltage as small as 0.01 volt causes full scale meter deflection.

At null, the differential voltmeter presents an "infinite" input impedance to the voltage under measurement, almost completely eliminating circuit loading.



NOTES:

1. UNLESS OTHERWISE SPECIFIED RESISTORS ARE ±10%, 1/2W AND SHOWN IN OHMS, K=1,000 M=1,000,000.
2. UNLESS OTHERWISE SPECIFIED CAPACITORS WITH VALUES OF 1.0 OR GREATER ARE IN MICROMICROFARADS, VALUES LESS THAN 1.0 ARE IN MICROFARADS.
3. ▭ INDICATES EQUIPMENT FRONT PANEL MARKING.
4. ⏚ INDICATES CHASSIS GROUND
   ⏚ INDICATES COMMON GROUND

4.133

Figure 12-5. — Electronic Multimeter AN/USM-[illegible]

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ure 12-6.—Differential Voltmeter, Model 803 D/AG.

A functional block diagram of the differential voltmeter is shown in figure 12-7. The principal circuit divisions are as follows:

1. A 500-volt d-c reference power supply
2. Precision voltage divider network
3. VTVM
4. Chopper-amplifier
5. Converter and converter power supply

The system circuitry is designed with two separate common returns. One of these, the return for the converter power supply and reference power supply, provides a safety factor for personnel and a capability for measuring a potential difference between two voltages. The other, which is the common return of the VTVM power supply, is connected to the known reference voltage output from the precision voltage divider network. This arrangement provides a constant d-c voltage of +108 volts across the differential amplifier regardless of the d-c potential applied to the grid.

D-C REFERENCE POWER SUPPLY.—A full wave rectifier with its associated filter network supplies a d-c voltage of approximately 1,000 volts to a conventional electron controlled voltage regulator. The regulated output is maintained at 500 volts ±0.01 per cent.

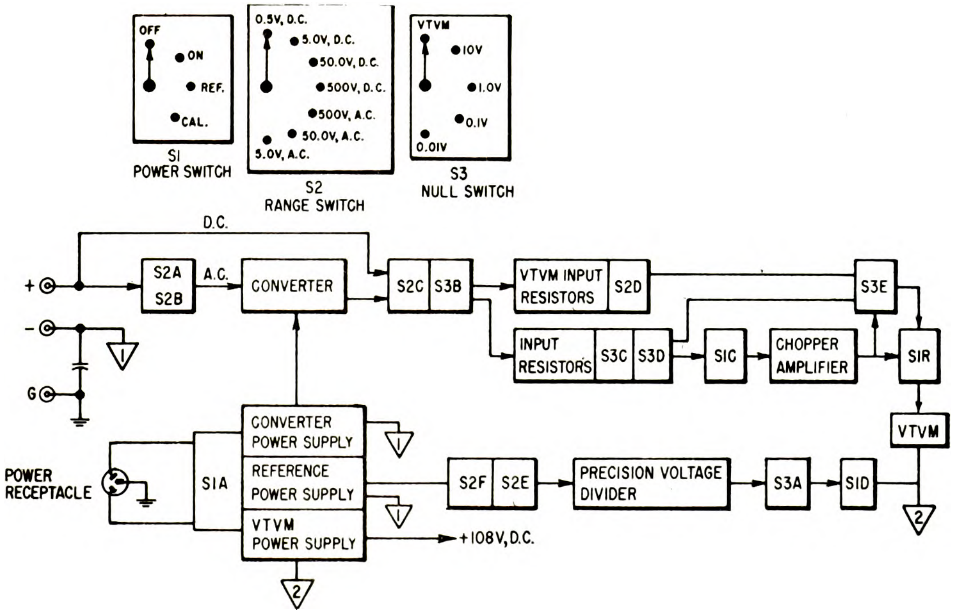

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Figure 12-7.—Differential voltmeter, functional schematic diagram.

In the 500 V DC position, the RANGE switch (S2E) passes this 500 volts directly to the precision voltage divider. In the 50 V DC, 5 V DC, and 0.5 V DC positions, range resistors S2F divide the reference voltage to 50, 5, and 0.5 volts d.c., respectively. In all a-c positions of the RANGE switch, only 5 volts of the reference supply are used, due to the fact that the maximum output of the a-c to d-c converter is 5 volts.

PRECISION VOLTAGE DIVIDER.— Each of the four precision voltages available from the reference supply must be made adjustable through a precision divider network so that unknown voltages may be nulled or matched exactly. The five decade resistor strings (fig. 12-8) accomplish this function.

Note that each string, with the exception of the first, parallels two resistors of the string that precedes it. Between the two wipers of S4, there is a total resistance of 40K and a total voltage of 100 volts d.c. with the RANGE switch in the 500 V DC position. Across the wipers of S5, S6, and S7, there are 10, 1, and 0.1 volts d.c., respectively. Switch S8 selects increments of 0.01-volt d.c. from the last decade. These voltages are reduced by a factor of 10 for each successively lower voltage range.

All resistors of each decade are matched and all decades are matched for each instrument, providing an overall divider accuracy of 0.005 percent.

With the NULL switch in any null range, the output of the precision voltage divider appears at the grid of one-half of the VTVM differential amplifier. A one two-hundredths ampere (5 milliampere) fuse protects this output.

VACUUM TUBE VOLTMETER.— When operating in the differential mode, output voltage

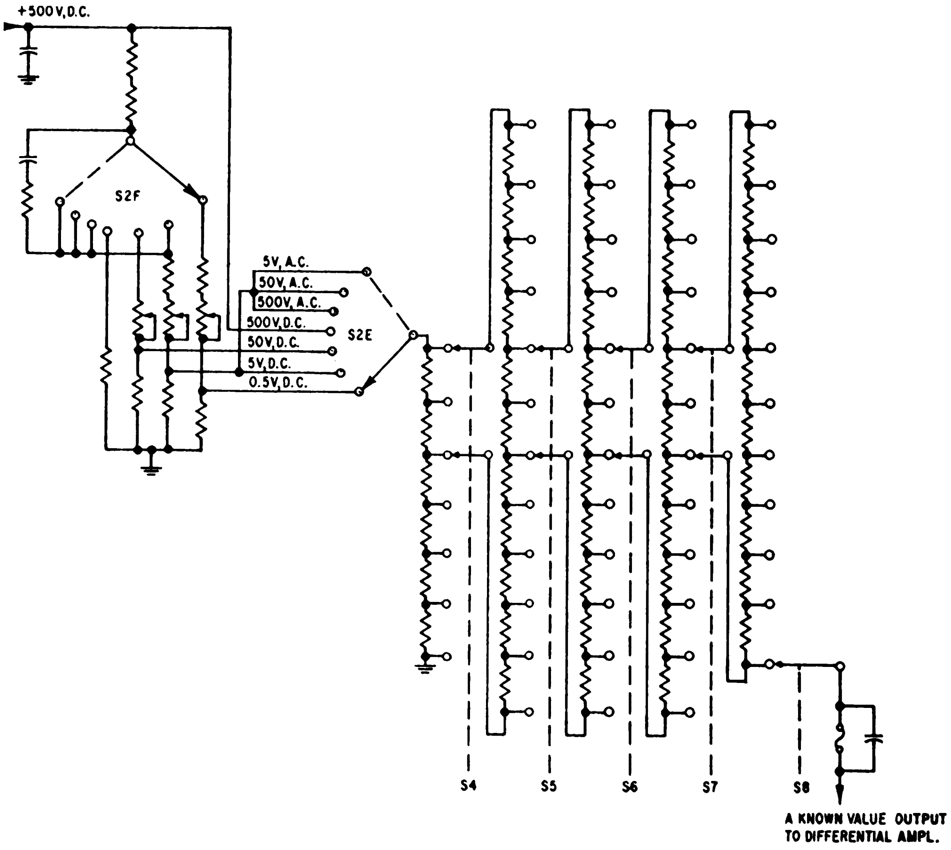

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Figure 12-8.— Precision voltage divider.

om the precision voltage divider appears on e grid of V4B, one-half of the differential nplifier. (See fig. 12-9.) The unknown voltage pears on the grid of V4A, the other half of e differential amplifier. Any difference between ese potentials is indicated by the meter coupled tween the cathodes of V4A and V4B. When the tput voltage exactly matches the unknown, the eter reads zero and no current is drawn from e source being measured, because the same tential exists on both sides of the input resisnces.

When used as a conventional VTVM, the grid V4B is connected to the 0-volt bus, or negative nding post. With the range switch in the 0.5 DC position, the unknown voltage appears rectly on the grid of V4A and the meter indites the approximate value of the unknown. Input divider resistors maintain the 0 to 0.5 grid voltage range for all instrument voltage ranges. The input resistance of the instrument in the VTVM position is 10 megohms.

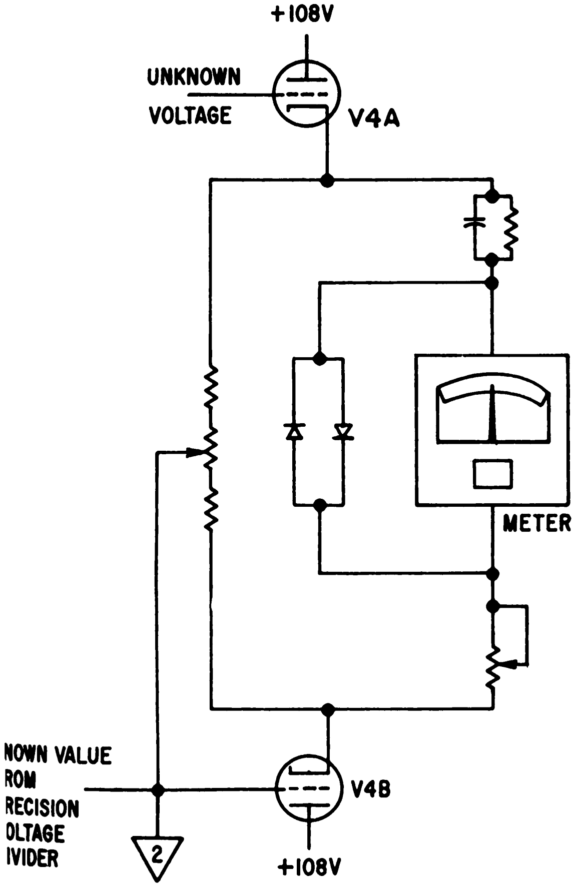

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Figure 12-9.—Differential amplifier.

CONVERTER.—All a-c measurements are made by first converting the a-c input to a d-c voltage. The converter provides a maximum d-c output of 5 volts for a maximum a-c input of 5 volts rms. In the 5 V AC position, range switch sections of S2A and S2B couple the converter amplifier input directly to the binding post. In the 50 V AC and 500 V AC positions, input attenuators reduce the unknown a.c. to provide a maximum of 5 volts a-c input to the first converter amplifier.

The overall frequency response of the converter is essentially flat from 30 Hz to 10 kHz.

MEGGERS

A megger is an instrument that applies a high voltage to the component under test and measures the current leakage of the insulation. Thus a capacitor or insulated cable can be checked for leakage under much higher voltages than an ohmmeter is capable of supplying. It consists of a hand-driven, d-c generator and an indicating meter. The name megger is derived from the fact that it measures resistances of many megohms.

There are various resistance ratings of meggers with full-scale values as low as 5 megohms, and as high as 10,000 megohms. Figure 12-10 shows the scale of a 100-megohm, 500-volt megger. Notice that the upper limit is infinity and that the scale is crowded at the upper end. The first scale marking below infinity represents the highest value for which the instrument can be accurately used. Thus, if the pointer goes to infinity while making a test, it means only that the resistance is higher than the range of the set.

There are also various voltage ratings of meggers (100, 500, 750, 1,000, 2,500, etc.). The most common type is the one with a 500-volt rating. This voltage rating refers to the maximum output voltage of the megger. The output voltage is dependent upon the speed of turning of the crank and armature. When the megger's armature rotation reaches a predetermined speed, a slip clutch will maintain the armature at a constant speed. The voltage rating is important, for the application of too high a voltage to even a good component will cause a breakdown. In other words, do not use a 500-volt megger to test a capacitor rated at 100 volts.

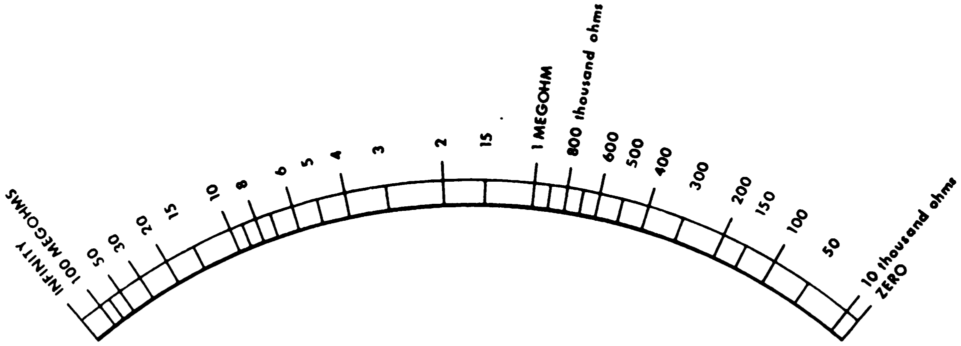


Figure 12-10.—Scale of 100-megohm, 500-volt megger.

Meggers are used to test the insulation resistance of conductors in which shorting or breaking down under high voltage is suspected. In some situations, meggers are used in the prevention of unnecessary breakdowns by maintaining a record of insulation resistance of power and high-voltage cables, motor and generator windings, and transmission lines. These records will reflect fluctuations in resistance and aid in determining when the components should be replaced to prevent a breakdown.

Meggers are used for testing capacitors whose peak voltages are not below the output of the megger. They are also used to test for high-resistance grounds or leakage on such devices as antennas and insulators.

A megger employing an a-c generator, a rectifier, and an ohmmeter circuit with a conventional d-c milliammeter (Insulation Test Set AN/PSM-2A) is illustrated in figure 12-11. The operation of the insulation test set is relatively simple.

1. Be sure that the apparatus, line, or circuit to be tested is disconnected from its power supply in accordance with safety instructions. Ground the apparatus, line, or circuit to be tested to discharge any capacitors connected to it.

2. Connect the spade type terminal lug of the black lead to the GND binding post of the test set.

3. Attach the alligator clip of the black test lead to the side of the circuit (under test) nearest ground potential.

4. Connect the spade-type terminal lug of the red lead to the L binding post of the test set.

5. Attach the alligator clip of the red test lead to the conductor to be tested.

6. Turn the crank in either direction at the minimum speed required to provide steady illumination of the indicator buttons.

7. Read the megohms of resistance offered by the material being tested. If the resistance is more than 1000 megohms at 500 volts d-c, the meter will remain at rest over the infinity mark (∞), indicating that the resistance of the insulation being tested is beyond the range of the meter.

Precautions to be followed in the use of the megger are as follows:

1. When making a megger test, the equipmen must not be energized. It must be disconnect entirely from the system before it is teste

2. Observe all rules for safety in preparin equipment for test and in testing, especially when testing installed high-voltage apparatu

3. Use well-insulated test leads, especial when using high-range meggers. After the lea are connected to the instrument and befor connecting them to the component to be teste operate the megger and make sure there is n leak between the leads. The reading should b infinity. Make certain the leads are not disconnected or broken by touching the test ends of th leads together while turning the crank slowl The reading should be approximately zero.

4. When using high-range meggers, take prop precautions against electric shock. There sufficient amount of capacitance in most electric equipment to "store up" sufficient energy fr the megger generator to give a very disagreeab

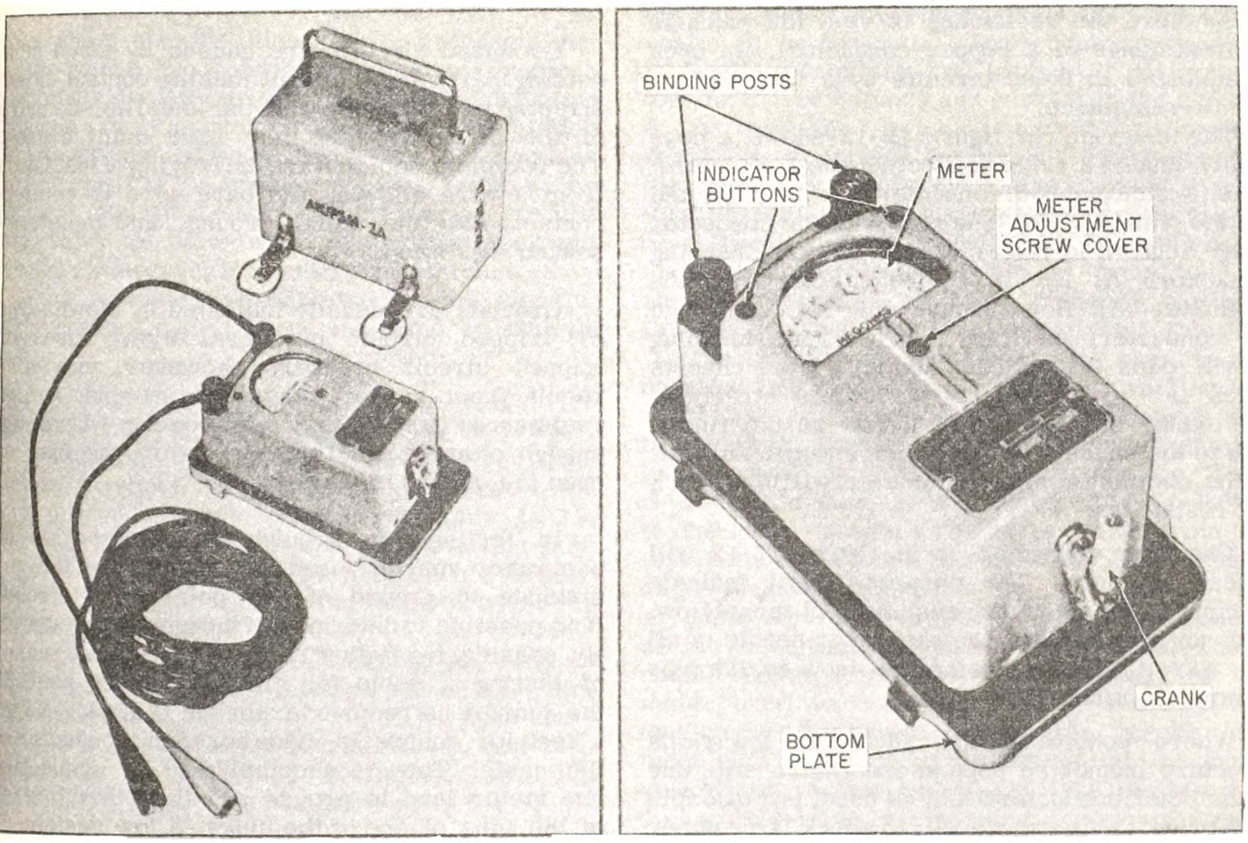


Figure 12-11.—Insulation Test Set AN/PSM-2A.

d even dangerous electric shock. Owing to a gh protective resistance in the megger, its en circuit voltage is not as dangerous, but re should be exercised.

5. Equipment having considerable capacitance ould be discharged before and after making gger tests in order to avoid the danger of ceiving a shock. This can be accomplished grounding or short circuiting the terminals of equipment under test.

CHNIQUES FOR METER USE

We have considered the more common meters; v let us consider some of the techniques ployed in their use. The techniques suggested re are not all-inclusive. You will find, as you relop your technical skill, there are other riations and techniques in use. As an example, isider the techniques for measureing current in ircuit. This can be done by placing an ammeter in series. It can also be accomplished by measuring the voltage across a resistor of known value. Then by application of Ohm's law, the current in the circuit can be calculated. This last technique has the advantage of eliminating the necessity of opening the circuit for placement of the ammeter.

Continuity Test

Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called CONTINUITY TESTING.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency a continuity test can readily be made using two sound-powered telephone handsets.

Normally continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper conductor). An open is indicated in these circuits by a very high or infinite resistance.

The diagram in figure 12-12 shows a continuity test of a cable connecting two fire control units. Notice that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power should be off. Checking conductors A, B, and C, the current from the ohmmeter will flow through plug No. 2, through the conductor, and plug No. 1. From this plug it will pass through the jumper to the chassis which is "grounded" to the ship's structure. The metal structure will serve as the return path to the chassis of unit 2 completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D in figure 12-12 will reveal an open. The ohmmeter will indicate maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left since it is a series type ohmmeter (reads right to left).

Where conditions are such that the ships structure cannot be used as the return path, one of the other conductors may be used. For example (referring to figure 12-12), to check D a jumper is connected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique will also reveal the open in the circuit.

Test for Grounds

Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic structure of the ship. Grounds may have many causes. The two most common are the fraying of insulation from a wire allowing the bare wire to come in contact with the metal ground, and moisture-soaked insulation.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than ground. A high resistance ground may also occur where not enough current can flow to rupture the fuse or open the circuit breaker.

In testing for grounds, a megger or an ohmmeter may be used. By measuring the resistance to ground of any point in a circuit, it is possible to determine if the point is grounded. By considering figure 12-12, one possible means of testing a cable for grounds can be seen. If the jumper is removed from pin D of plug No. 1, a test for gounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance will indicate that a pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible for a conductor may be grounded through the unit.

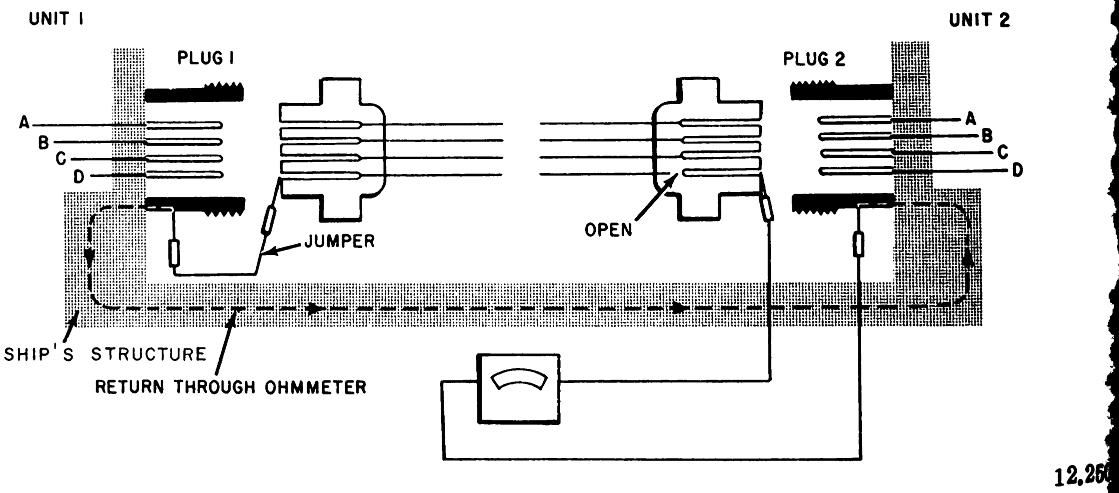


Figure 12-12.—Continuity test.

Test for Shorts

A short circuit, other than a grounded one, s one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation nay touch and cause a short. Too much solder n the pin of a connector may short to the djacent pin. In a short circuit enough current nay flow to blow a fuse or open a circuit reaker. However, it is entirely possible to have short between two cables carrying signals; uch a short will not be indicated by a blown use.

As when checking for continuity, the device sed for checking for a short is the ohmmeter. y measuring the resistance between two conuctors, a short between them may be detected y a low resistance reading. In figure 12-12, removing the jumper and disconnecting both lugs, a short test may be made. This is perrmed by measuring the resistance between the vo suspected conductors.

Shorts occur in many components, such as ansformers, motor windings, capacitors, etc. he major test method for detecting such comnents is a resistance measurement, and then mparing the indicated resistance with the sistance given on schematics or in the equipent OP.

ltage Test

The voltage test must be made with the power plied; therefore, the prescribed safety preutions MUST be followed to prevent injury to rsonnel and damage to the equipment. You ll find in your maintenance work that the ltage test is of utmost importance. It is used t only in isolating casualties to major comnents but also in the maintenance of subsemblies, units, and circuits. Before checking circuit voltage, a check on the voltage of the wer source should be made to be sure that the rmal voltage is being impressed across the cuit.

Obviously, the voltmeter is used for voltage ts. In using the voltmeter make certain that meter used is designated for the type current c or d-c) to be tested and has a scale of equate range. Since defective parts in a circuit y cause higher than normal voltages to be sent at the point of test, the highest voltter range available should be used at first. ce a reading has been obtained, determine if a lower scale can be employed without damaging the meter movement. If so, use the lower scale, so as to obtain a more accurate reading.

Another consideration in the circuit voltage test is the resistance and current in the circuit. A low resistance in a high current circuit would result in considerable voltage drop, whereas the same resistance in a low current circuit may be negligible. Abnormal resistance in part of a circuit can be checked with either an ohmmeter or a voltmeter. Where practical, an ohmmeter should be used, because the test is then carried out with the circuit "dead."

The majority of the electronics circuits encountered in fire control equipment will be low current circuits, and most voltage readings will be direct current. Also many of the schematics indicate the voltages at many test points. Thus if a certain stage is suspected and you desire to check the voltage, a voltmeter placed from the test point to ground should read the voltages as given on the schematic.

Some OPs also contain voltage charts where all the voltage measurements are tabulated. These charts usually indicate the sensitivity of the meter used to obtain the voltage readings for the chart. To obtain comparable results, the technician must use a voltmeter of the same sensitivity as that specified. Make certain that the voltmeter is not loading the circuit while taking a measurement. If the meter resistance is not considerably higher than the circuit resistance, the reading will be markedly lower than the true circuit voltage. (To calculate the meter resistance, multiply the rated ohms per volt sensitivity value of the meter by the scale in use. For example, a 1,000 ohms-per-volt meter set to the 300-volt scale will have a resistance of 300,000 ohms.)

Resistance Test

Before checking the resistance of a circuit or of a part, make certain that the power has been turned off and that capacitors in an associated circuit are discharged. To check continuity, always employ the lower ohmmeter range. If a high range is used, the meter may indicate zero even though appreciable resistance is present in the circuit. Conversely, to check a high resistance, use the highest scale, since the low range scale may indicate infinity though the resistance is less than a megohm.

In making resistance tests, take into account that other circuits that contain resistances and capacitance may be in parallel with the circuit to be measured, in which case an erroneous conclusion may be drawn from the reading obtained. Remember, a capacitor will block the d-c flow from the ohmmeter. To obtain an accurate reading if other parts are connected across the suspected circuit, one end of the circuit to be measured should be disconnected from the equipment. For example, many of the resistors in major components and subassemblies are connected across transformer windings. To obtain a valid resistance measurement, the resistor to be measured must be isolated from the shunt resistances.

Resistance tests are also used for checking a part for grounds. In these tests, the parts should be disconnected from the rest of the circuit so that no normal circuit ground will exist. It is not necessary to dismount the part to be checked. The ohmmeter, which is set for a high resistance range, is then connected between ground and each electrically separate circuit of the part under test. Any resistance reading less than infinity indicates at least a partial ground. Capacitors suspected of being short circuited can also be checked by a resistance measurement. To check a capacitor suspected of being open, temporarily shunt a known perfect capacitor across it, and recheck the performance of the circuit.

PRECAUTIONS IN USE OF METERS

The following are guides for the proper use of meters.

1. An ammeter is always connected in series—NEVER in parallel.
2. A voltmeter is connected in parallel.
3. An ohmmeter is NEVER connected to a live circuit.
4. Polarity must be observed in the use of a d-c ammeter or a d-c voltmeter.
5. Meters should be viewed directly from the front. When viewed from an angle off to the side, an incorrect reading will result because of optical parallax.
6. Always choose an instrument suitable for the measurement desired.
7. Select the highest range FIRST and then switch to the proper range.
8. In using a meter, choose a scale which will result in an indication as near midscale as possible.
9. Do not mount or use instruments in the presence of a strong magnetic field.
10. Remember, a low internal resistance voltmeter (low sensitivity) may shunt the circuit being measured and result in incorrect readings.

BRIDGE CIRCUITS IN METERS

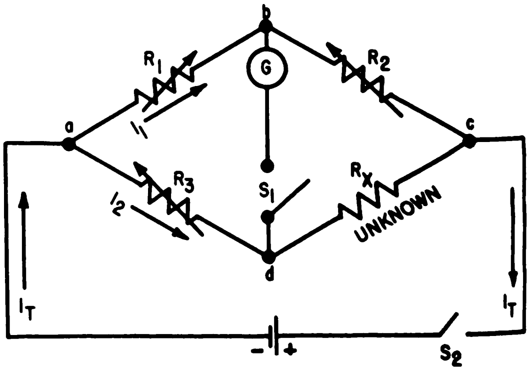
An instrument employing a bridge circuit should be used in the measurement of resistance, capacitance, and inductance where a high degree of accuracy is desired. Bridge circuits are used in both a-c and d-c measuring instruments; both types are discussed in this section.

Use of D-C Bridges

A type of circuit that is widely used for precision measurements of resistance is the Wheatstone bridge. This type bridge is discussed in detail in Basic Electricity, NavPers 10086-B. We shall discuss only its use in determining a value of resistance for an unknown resistor. The circuit diagram of a Wheatstone bridge is shown in figure 12-13.

In figure 12-13; R_1, R_2, and R_3 are precision variable resistors and R_x is the resistor whose value is unknown. The galvanometer G is inserted across terminals b and d to indicate the condition of balance. When the bridge is properly balanced there is no difference of potential between terminals b and d. Thus, the galvanometer deflection when the switches S_1 and S_2 are closed, will be zero.

The operation of the bridge is explained in a few logical steps. When the switch S_2 is closed, current will flow from the negative terminal of the battery to point a. Here the current will divide as in any parallel circuit,



12.25

Figure 12-13.—D-C Wheatstone bridge circuit

part of it passing through R_1 and R_2 and the remainder passing through R_3 and R_x. The two currents, labeled I_1 and I_2, unite at point c and return to the positive terminal of the battery. The value of I_1 depends on the sum of resistances R_1 and R_2 while the value of I_2 depends on the sum of resistances R_3 and R_x. R_1, R_2, and R_3 are adjusted so there will be no deflection of the galvanometer needle when both switches are closed. Thus, there is no difference of potential between points b and d.

This means that the voltage drop across R_1 (E_1) is the same as the voltage drop across R_3 (E_3). By similar reasoning, the voltage drops across R_2 and R_x, that is E_2 and E_x, are also equal. Expressed algebraically,

$$E_1 = E_3$$

or

$$I_1 R_1 = I_2 R_3$$

and

$$E_2 = E_x$$

or

$$I_1 R_2 = I_2 R_x$$

Dividing the voltage drop across R_1 and R_3 by the respective voltage drop across R_2 and R_x,

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_x}$$

Simplifying

$$\frac{R_1}{R_2} = \frac{R_3}{R_x}$$

$$R_x = \frac{R_2 R_3}{R_1}$$

The resistance values of R_1, R_2, and R_3 are readily determined from the markings on the standard resistors, or from the calibrated dials if a dial type bridge is used. Then, after the bridge has been properly balanced, the unknown resistance may be determined by using the formula.

Use of A-C Bridges

There is a wide variety of a-c bridge circuits that may be used for the precision measurements of resistance, capacitance, and inductance. Before discussing a specific bridge, let's look at a-c bridges in terms of the functions they perform.

A-C RESISTANCE BRIDGE.—The Wheatstone bridge discussed previously under d-c bridge circuits is also applicable to circuits utilizing alternating current, as shown in figure 12-14.

As shown in figure 12-14, an a-c signal generator is used as the source of voltage. Current from the generator G passes through resistors R_1 and R_2, which are known as the ratio arms, and through R_s and R_x. R_s is an adjustable standard resistance and R is the unknown resistance. When the voltage-drops across R_1 and R_s are equal, the voltage-drops across R_2 and R_x are also equal, and no difference of potential exists across the meter. As discussed in the section on d-c bridges, when no voltage appears across the indicating device, the following ratio is true:

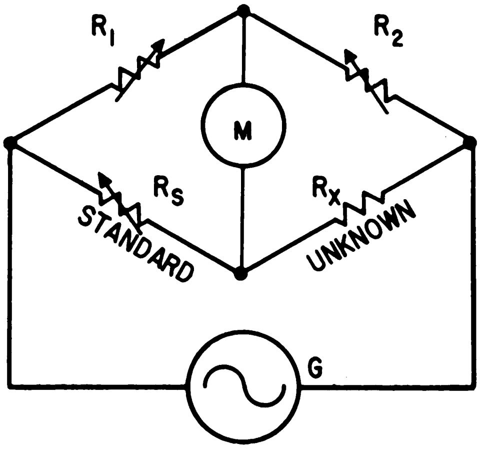
$$\frac{R_1}{R_2} = \frac{R_s}{R_x}$$

and

$$R_x = \frac{R_s R_2}{R_1}$$

It is necessary to select the proper resistance values of R_1, R_2, and R_s so that the meter will remain centered when power is applied. With these values of resistance known, the value of the unknown resistance may be found.

A-C CAPACITANCE BRIDGE.—The value of an unknown capacitance C_x may be determined



12.252

Figure 12-14.—A-C resistance bridge circuit.

by a capacitance bridge (fig. 12-15). The ratio arms, R_1 and R_2, are accurately calibrated resistors. C_s is a standard capacitor whose capacitance is known, R_s is the equivalent series resistance of the standard capacitor, and R_x is the equivalent series resistance of the unknown capacitor.

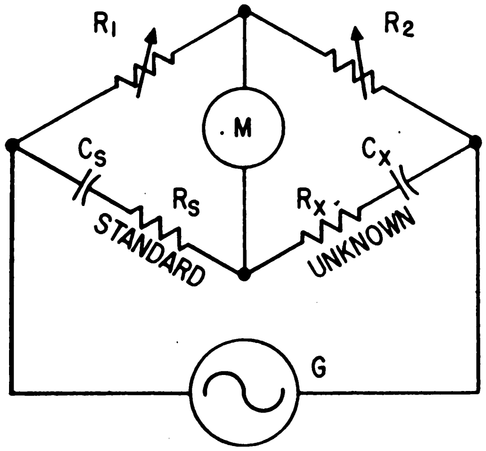
With the a-c signal applied to the bridge, R_1 and R_2 are varied until a zero reading is seen on the meter. Zero deflection indicates that the bridge is balanced. (Note: In actual practice the variables are adjusted for a minimum reading since the phase difference between the two legs will not allow a zero reading.) Since current varies inversely with resistance and directly with capacitance, an inverse proportion exists between the four arms of the bridge. Thus,

$$\frac{R_1}{R_2} = \frac{C_x}{C_s}$$

or

$$C_x = \frac{R_1 C_s}{R_2}$$

Since R_1 and R_2 are expressed in the same units, $\frac{R_1}{R_2}$ becomes a simple multiplication factor. This equation will give a numerical value for C_x and the answer will be in the same units as C_s (farad, microfarad, etc.).



12.253

Figure 12-15.—A-C capacitance bridge.

Similarly, the following direct proportion exists between the four arms of the bridge:

$$\frac{R_1}{R_2} = \frac{R_s}{R_x}$$

or

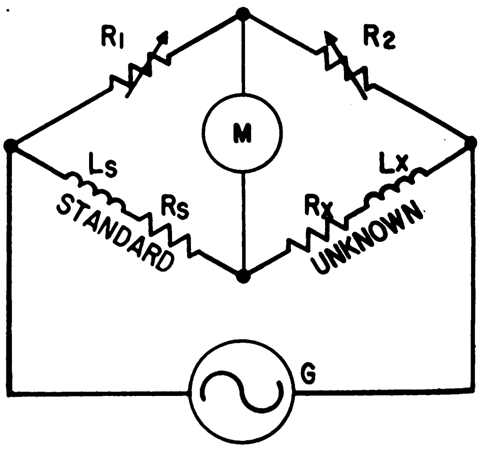
$$R_x = \frac{R_2 R_s}{R_1}$$

Thus the unknown resistance and capacitance, R_x and C_x, can be estimated in terms of the known resistance R_1, R_2, and R_s and the known capacitance C_s.

INDUCTANCE BRIDGE.—The value of an unknown inductance L_x may be determined by means of the simple bridge circuit shown in figure 12-16. The ratio arms R_1 and R_2 are accurately calibrated resistors. L_s is a standard inductor whose inductance is known, R_s is its resistance. R_x represents the resistance of the unknown inductor.

Referring to figure 12-16, the a-c signal is applied to the bridge while the two variable resistors R_1 and R_2 are adjusted for a minimum or zero deflection of the meter, indicating a condition of balance. When the bridge is balanced,

$$\frac{R_1}{R_2} = \frac{L_s}{L_x}$$



12.254

Figure 12-16.—A-C inductance bridge.

or

$$L_x = \frac{R_2 L_s}{R_1}$$

and

$$\frac{R_1}{R_2} = \frac{R_s}{R_x}$$

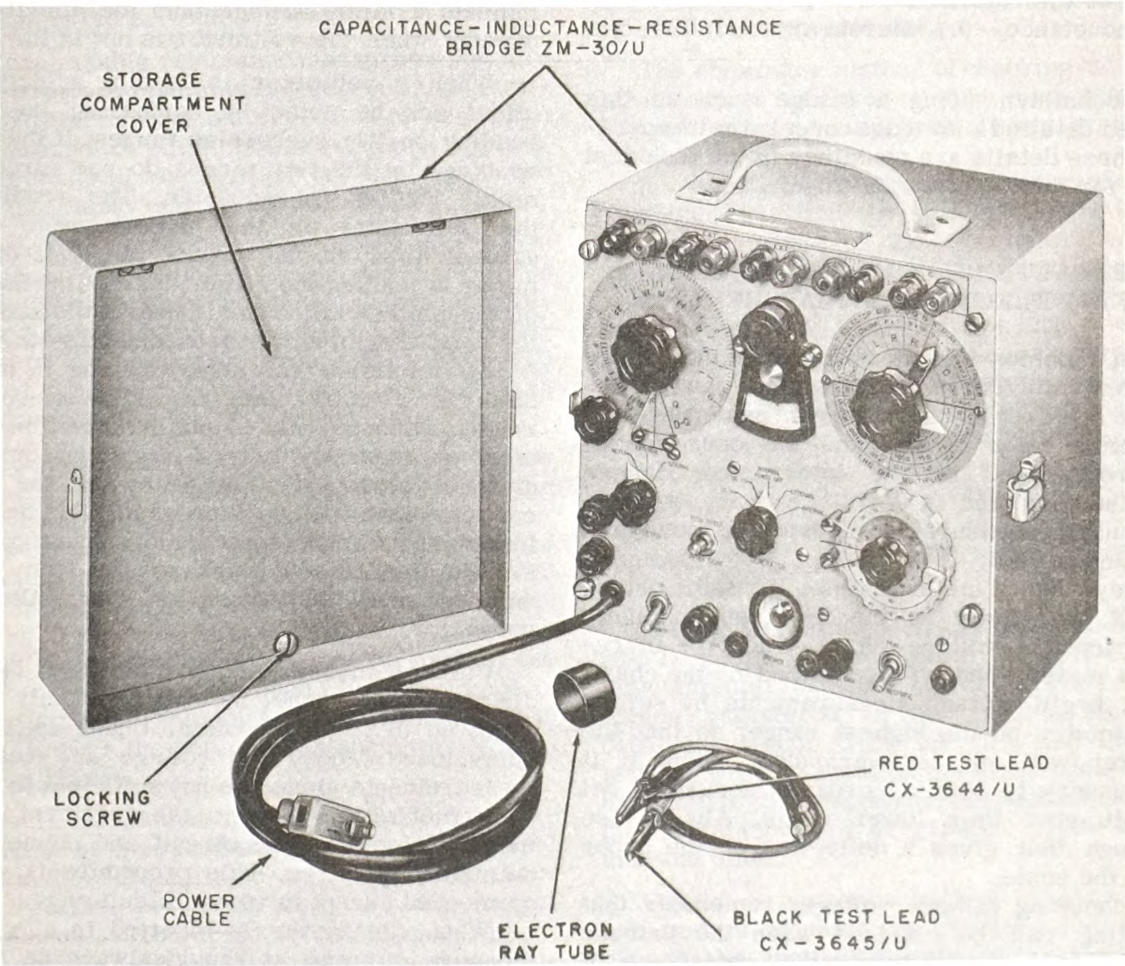
or

$$R_x = \frac{R_2 R_s}{R_1}$$

Thus, the unknown resistance and inductance can be estimated in terms of the known resistance R_1, R_2, and R_s and the known inductance L_s.

R-C-L Bridge AN/URM-90

The bridge most likely to be encountered by the FTM is the R-C-L Bridge AN/URM-90 (fig. 12-17). The AN/URM-90 is a self-contained, dial face instrument used in electrical and electronic work where the values and characteristics of resistors, capacitors, and inductors must be accurately measured. D-c measurements are obtained by means of a galvanometer. An electron-ray tube (type 6U5) is utilized for a-c


CAPACITANCE-INDUCTANCE-RESISTANCE BRIDGE ZM-30/U
STORAGE COMPARTMENT COVER
LOCKING SCREW
POWER CABLE
ELECTRON RAY TUBE
RED TEST LEAD CX-3644/U
BLACK TEST LEAD CX-3645/U

20.335(167)

Figure 12-17.—R-C-L Bridge AN/URM-90.

measurements. The electron-ray tube provides a shadowed angle type presentation to indicate conditions of bridge balance. When the shadowed angle is wide, an unbalanced condition exists. The calibrated dials are adjusted so as to obtain a narrow shadowed angle which indicates a balanced bridge.

The AN/URM-90 has a 1000 Hz internal power source. If, however, measurements are desired at some other frequency, the set has an operating frequency range of 100 to 10,000 Hz when used in conjunction with an appropriate audio oscillator. The range of measure for each function is as follows:

1. Resistance—0.1 milliohm to 11 megohms.
2. Capacitance—0.1 micro-microfarad to 1100 microfarads.
3. Inductance—0.1 microhenry to 1100 henrys.

A technician using a bridge such as this will need detailed knowledge concerning its operation. These details are contained in the technical manual for the test set, TM-2646AC1.

PRECAUTIONS AND PROCEDURES IN MAKING ELECTRICAL MEASUREMENTS

Most troubles can be found by taking voltage measurements. These measurements can be made easily, since they are always made between two points in a circuit and the operation of the circuit need not be interrupted. Unless otherwise indicated in a voltage chart, voltages are usually measured between the indicated points and ground.

Always use a meter that has the same ohms-per-volt sensitivity as the one used originally to develop the voltage chart. The type of reference meter used will be stated on the chart. Always begin voltage measurements by setting the voltmeter on the highest range, so that the voltmeter will not be overloaded. Then, if it is necessary to obtain increased accuracy, set the voltmeter to a lower range. Always use the range that gives a deflection on the upper part of the scale.

In checking cathode voltage, remember that a reading can be obtained when the cathode resistor is actually open, the resistance of the meter acting as a cathode resistor.

Certain precautions must be followed when measuring voltages above a few hundred volts since high voltages are dangerous and can be fatal. When it is necessary to measure high voltages, observe the following rules.

1. Connect the ground lead to the voltmeter.
2. Place one hand in your pocket.
3. If the voltage is more than 300 volts, shut off the power, connect the hot test lead, step away from the voltmeter, turn on the power, and note the reading on the voltmeter. Do not touch any part of the voltmeter, particularly when it is necessary to measure the voltage between two points both of which are above ground.

It is essential that the voltmeter resistance be at least 10 times as large as the resistance of the circuit across which the voltage is measured. If the voltmeter resistance is comparable to the circuit resistance, the voltmeter will indicate a lower voltage than the actual voltage present when the voltmeter is not in the circuit.

When a voltmeter is loading a circuit, the effect can be noted by comparing the voltage reading on two successive ranges. If the voltage readings on the two ranges do not agree, voltmeter loading is excessive. The reading (not the deflection) on the highest range will be greater than on the lowest range. If the voltmeter is loading the circuit heavily, the deflection of the pointer will remain nearly the same when the voltmeter is shifted from one range to another.

To minimize voltmeter loading in high resistance circuits, use the highest voltmeter range. Although only a small deflection will be obtained (possibly only 5 divisions on a 100-division scale), the accuracy of the voltage measurement will be increased. The decreased loading of the voltmeter will more than compensate for the inaccuracy which results from reading only a small deflection on the scale of the voltmeter.

Current measurements other than those indicated by the panel meters ordinarily are not required in troubleshooting. Under special circumstances where the voltage and resistance measurements alone are not sufficient to localize the trouble, a current measurement can be made by opening the circuit and connecting an ammeter in series. This procedure is not recommended except in very difficult cases.

When the meter is inserted in a circuit to measure current, it should always be inserted away from the RF end of the resistor. For example, when measuring plate current, do not insert the meter next to the plate of a tube, but insert it next to the end of the resistor which connects to the power supply. This precaution is necessary to keep the meter from affecting RF voltages.

CAUTION: A meter has least protection against damage when it is used to measure current. Always set the current range to the highest value. Then, if necessary, decrease the range to give a more accurate reading. Avoid working close to full-scale reading because this increases the danger of overload.

In most cases, the current to be measured flows through a resistance which is either known or can be measured with an ohmmeter. The current flowing in the circuit can be determined by dividing the voltage drop across the resistor by its resistance value. The drop across the cathode resistor is a convenient method of determining the cathode current.

Before making resistance measurements, turn off the power. An ohmmeter is essentially a low-range voltmeter and battery. If it is connected to a circuit to which power is being applied, the needle will be forced off scale and the meter movement may be burned out.

Capacitors must always be discharged before resistance measurements are made. This is very important when checking power supplies that are disconnected from their load. The discharge of the capacitor through the meter will burn out the meter movement and in some cases may endanger life.

It is important to know when to use the low resistance range of an ohmmeter. When checking circuit continuity, the ohmmeter should be set on the lowest range. If a medium or high range is used, the pointer may indicate zero ohms, although the resistance may be as high as 500 ohms. When checking high resistances or measuring the leakage resistance of capacitors or cables, the highest range should be used. If a low range is used in this case, the pointer will indicate infinite ohms, although the actual resistance may be less than a megohm.

When a resistance is measured and the value is found to be less than expected, make a careful study of the schematic to be certain that there are no resistances in parallel with the one that has been measured. Before replacing a resistor because its resistance measures too low, disconnect one terminal from the circuit and measure its resistance again to make sure that the low reading does not occur because some part of the circuit is in parallel with the resistor.

When checking a grid resistance, a false reading may be obtained if the tube is still warm and the cathode is emitting electrons. Allow the tube to cool, or connect the ohmmeter test leads so that the negative test lead is applied to the grid.

Tolerance is the normal difference to be expected between the rated value of the resistor and its actual value. Most general purpose resistors have a tolerance of 20 percent. For example, the grid resistor of a stage might have a rated value of 1 megohm. If the resistor were measured and found to have a value between 0.8 and 1.2 megohms, it would be considered normal. Some precision resistors and potentiometers are used. When a resistor is used whose value must be very close to its rated value, the tolerance is stated on the diagram and in the maintenance parts list.

The ohmmeter method of checking electrolytic capacitors is a method used by many technicians if precision test equipment is not available or close at hand.

A resistance measurement is made on the discharged electrolytic capacitor, using the high-resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is a leakage present between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance will be greater in one direction than the other.

Should a capacitor indicate a short circuit, one end of it must be disconnected from the circuit and another resistance reading be made to determine if the capacitor is actually at fault.

Unless your ohmmeter has a very high resistance scale you will not see a deflection of the meter when checking small capacitors. Even a scale of R x 10,000 is not sufficient for very small ones; the smaller the capacity the less leakage across the plates, therefore the more the resistance.

TUBE TESTERS

Electron tubes do not last indefinitely. Coated cathodes lose their power to emit electrons because the coating flakes off. Likewise, impregnated emitters of filament type tubes become depleted with age. There are other factors that cause electron tubes to function improperly—for example, defective seals permit air to leak into the tube and "poison" the emitting surface, and vibration or excessive voltage may cause internal shorts or opens. Whenever electronic equipment operates subnormally one of the first maintenance procedures is to check the tubes with a tube tester. This often results in finding weak tubes and replacing them prior to failure. A new tube should be tested before it is used.

Two types of tube testers are in general use. One type, the EMISSION TYPE tester, indicates the relative value of a tube in terms of its ability to emit electrons from the cathode. The second and more accurate type is the MUTUAL-CONDUCTANCE (or transconductance) tube tester. This tube tester not only gives an indication of the electron emission but also indicates the ability of the grid voltages to control he plate current.

The end of a useful life of a tube is usually preceded by a reduction in electron emissivity—that is, the cathode no longer supplies the number of electrons necessary for proper operation of the tube. In the emission tester, the proper voltages are applied to each electrode in the tube, and a meter indicates the plate current. If the tube has an open element or is at the end of its useful life, the emission tester gives an indication of this defect in the lower, or reject, portion of the meter scale.

A tube may have normal emission and still not operate properly because tube efficiency depends on the ability of the grid voltage to control the plate current. The emission type tester indicates only the plate current and not the ability of the grid to control the plate current. The transconductance type tube tester, however, indicates how the tube operates, not merely the condition of the emitting surface.

The terms "mutual conductance" and "transconductance" are used interchangeably in many texts. The Navy Department prefers transconductance, but many commercial tube testers are marked "mutual conductance."

When the prefix "dynamic" is used, as in "dynamic transconductance," it means that the characteristics of the tube in operation are being tested. The difference between the dynamic and static characteristics lies in the effect produced by the load impedance on the operation of the tube. Most tube testers, other than the emission type, test the dynamic characteristics by placing the tube in a working circuit.

Tube Tester TV-10/U is used extensively aboard SMS ships. It will be typical of any others that you may encounter.

TUBE TEST SET TV-10/U

The technical manual NAVSHIPS 93069 is issued with each TV-10/U tester. It contains complete information about the tester including schematic diagrams. In this discussion emphasis will be placed on the technical characteristics of the tester with a brief explanation of the various tests performed on electron tubes.

The TV-10/U is a portable tube tester of the dynamic mutual conductance type designed to test and measure the mutual conductance values of electron tubes of the receiving types and many of the smaller transmitting types. Noise test jacks (J103 and J104) are included for checking noisy tubes.

Tests that can be made on the TV-10/U are (1) dynamic mutual conductance test, (2) shorts test, (3) gas test, (4) noise test, (5) rectifier test, and (6) pilot lamp test.

The following technical data apply to the TV-10/U:

Meter range....................	0 to 30,000 micromhos.
Tubes..........................	2 (1 type 83, 1 type 5Y3WGTA).
Power consumption........	75 watts at 60 Hz minimum.
Power supply:	
Voltage....................	105 to 125 volts, single phase.
Frequency..................	50 to 400 Hz.

Tester Controls

Figure 12-18 shows the TV-10/U tester. Refer to this figure when studying the functions of the various controls, as follows:

a. Power input to the test set is controlled by the POWER switch, S111. The PILOT lamp (DS102) serves as an ON-OFF indicator for the equipment.

b. The LINE ADJUST, R-122, controls the input voltage to the power transformer, T101, for proper standardization of the tube test circuits.

c. THE ROLL CHART N101, located at the bottom of the panel, is operated by a phenolic gear which protrudes through the panel in the lower righthand corner. Appropriate column headings on the panel just above the index window provide easy reference to tube test data printed on the roll chart.

d. The FILAMENT VOLTAGE switch, S108, provides a selection of filament or heater voltages from 0.6 volts through 117 volts ac in eighteen steps. Another position on this switch, marked BLST., provides for testing ballast tubes. An OFF position is also provided.

e. SELECTORS: FILAMENT S107, FILAMENT S106, GRID S105, PLATE S104, SCREEN S103, CATHODE S102, and SUPPRESSOR S101 provide proper switching of the internal circuits to apply correct test voltages to the various pins of the tube under test.

f. BIAS control R130 is used to adjust the bias voltage applied to the tube under test to the proper value.

g. SHUNT control, a potentiometer R123, controls the sensitivity of the meter circuit to the proper level of testing rectifier and diode type tubes.

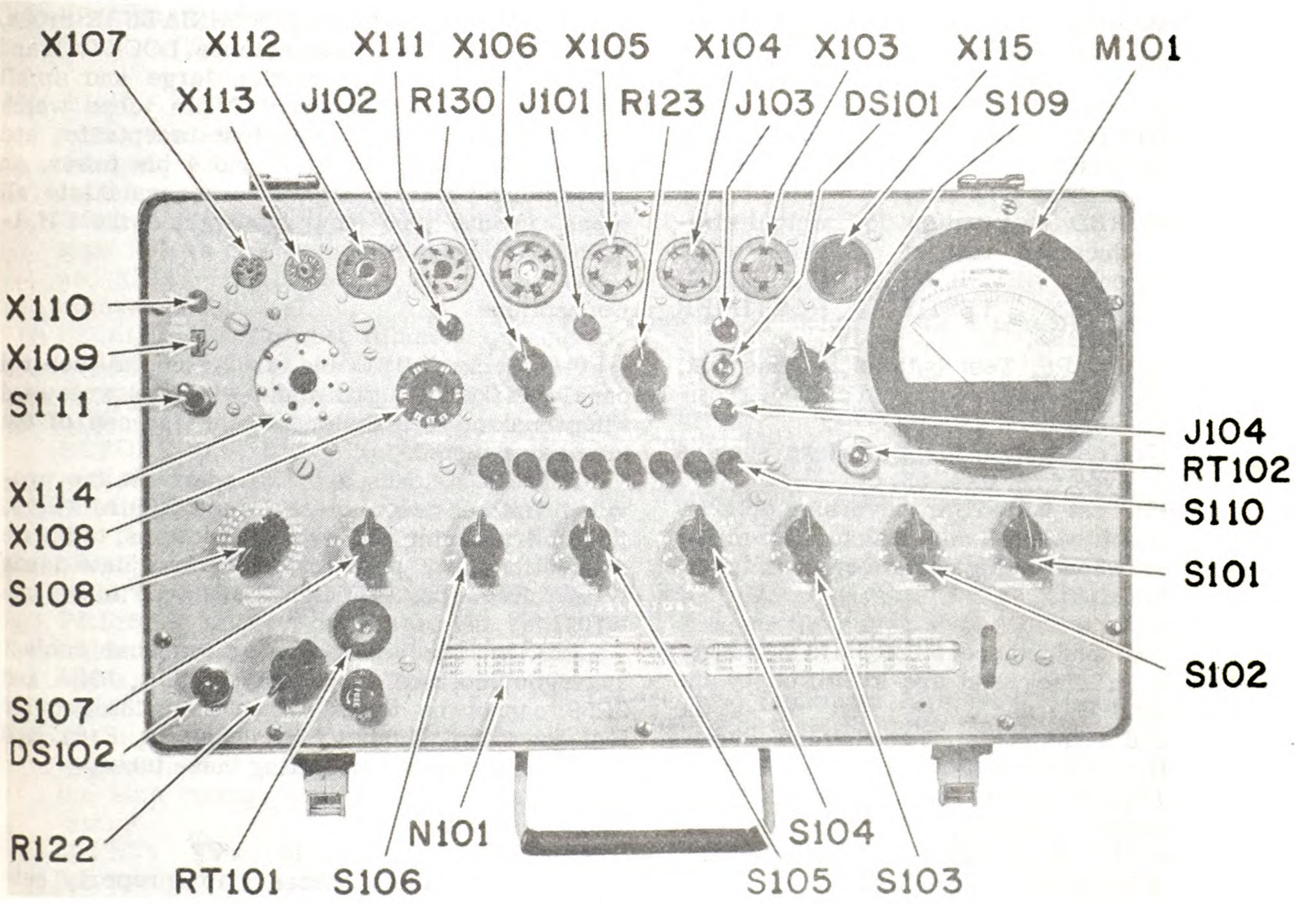


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Figure 12-18.—Electron Tube Test Set TV-10/U, showing controls by symbol designation.

h. SHORTS—MICROMHOS SWITCH, S109, selects the proper range of mutual conductance in micromhos for the tube under test as indicated on the roll chart. When this switch is set in the "A" or SHUNT position, the SHUNT potentiometer is connected into the circuit and must be set as indicated by the chart. This position of the switch is used when testing rectifier or diode type tubes. The letters "A", "B", "C", "D", and "E" at the five positions of the MICROMHOS switch indicate the meter scale on which the reading is to be made. In positions "B", "C", "D", and "E" fixed shunt resistors are connected across the meter and proper signal voltages are selected for the various ranges of micromhos. This switch also has five short test positions which connect the various elements of the tube under test to the short test circuit containing the neon indicator lamp (DS101).

i. Push button switches located in the center of the panel actuate the final circuit selector switches for the type of test to be made as follows:

(1) P1: LINE ADJUST test button (S110).
(2) P2: Test button for detector type diodes such as type 6H6.
(3) P3: RED test button for mutual conductance test of amplifier tubes only. NEVER USE THIS BUTTON WHEN TESTING RECTIFIER TUBES.
(4) P4 and P5: Test buttons for gas test.
(5) P6: Test button for cold cathode rectifiers such as type OZ4.
(6) P7: Test button for rectifiers such as type 5Y3, 6X4, 83, etc.
(7) P8: Test button for reversing polarity of voltage applied to the meter when testing certain types of tubes.

j. METER M101.

The mutual conductance, MICROMHOS, ranges are printed in black and are identified by the small letters "B", "C", "D", and "E" at the right hand end of the scale. These letters correspond with the SCALE letters at the positions of the MICROMHOS switch S109. Scale "B" 0 to 3000 micromhos, scale "C" 0 to 6000 micromhos, scale "D" 0 to 15,000 micromhos, and scale "E" 0 to 30,000 micromhos.

The "A" scale is for checking rectifier and diodes, and is used when the MICROMHOS switch is in the SHUNT or "A" position.

Indicator Lamps

The PILOT indicator (DS102) contains a miniature lamp which glows when the power switch is in the ON position. The neon short lamp (DS101) serves to indicate and locate shorted tube elements. The FUSE lamp (RT101) serves both as a protective fuse and an overload indicator. This lamp will flash brightly when an overload is placed on the test set or the tube under test. The BIAS FUSE lamp (RT102) protects the BIAS control R130. An accidental overload will cause the lamp to glow. An excessive or prolonged overload will burn out the fuse lamp, and replacement will be ncessary.

Test Sockets

The tube sockets (X103-X115) are grouped along the top edge of the panel. The sockets and their descriptive names are as follows: SUBMINIATURE tubes, 7 PIN MINIATURE tubes, 9 pin NOVAL base miniature tubes, LOCKTAL and OCTAL tubes, a combination large and small radius socket for standard 7 pin tubes which also provides a pilot lamp test receptacle, and sockets for standard 6, 5 and 4 pin tubes. An acorn tube socket designed to accommodate all tubes of this type is at the right of the FILAMENT voltage switch.

Connections

Two jacks (J101 and J102) on the control panel marked G (grid) and P (plate) are used when making connections to the top cap of the tube being tested.

Three test leads and two adapters are provided in the cover of the case, figure 12-19. For tubes having top grid connections, top plate connections, or both, use grid and plate leads W102 and W103. For lighthouse type tubes use W101.

Due to special bases or unusual contact arrangement tube types 3E29, 829A, 832A and 2C39 cannot be tested directly in the regular test sockets. Tube socket adapters E101 and E102 are provided for testing these tubes.

Tube Test Data

All information necessary for properly setting the tube test controls for the various tube types is tabulated on the roll chart (N101, figure 8-18) in nine columns under the following headings, reading from left to right:

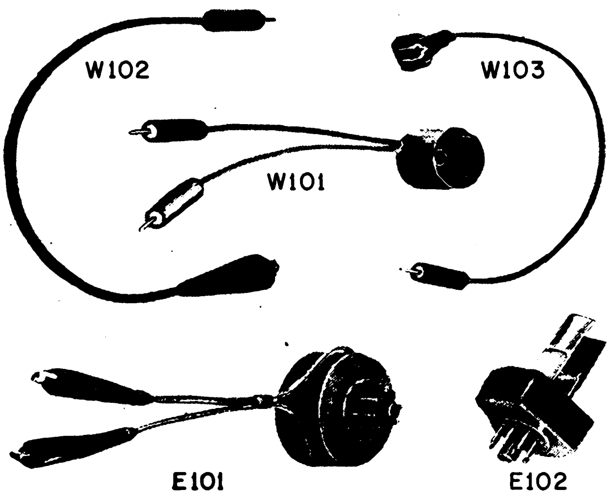

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Figure 12-19.—Test leads and adapters.

(1) TUBE TYPE: All currently available type numbers which the TV-10A/U is designed to test are listed numerically in this column starting with type 00A and continuing through type XXL. Tubes having type letters only instead of numbers, such as XXB, are listed at the end of the numerical listings.
(2) FILAMENT: Correct filament or heater voltages for the tube types listed are shown in this column. FILAMENT VOLTAGE switch must be adjusted accordingly BEFORE inserting a tube in any of the test sockets.
(3) SELECTORS: In this column are listed the correct settings for the two FILAMENT selector switches, and the GRID, PLATE, SCREEN, CATHODE, AND SUPPRESSOR selector switches. The settings follow the same order in which the switches appear on the panel reading from left to right.
(4) BIAS: This column lists the proper settings for the BIAS control which adjusts the bias voltage applied to the tube under test.
(5) SHUNT: This column lists the settings for the SHUNT potentiometer, which controls the sensitivity of the meter circuit. Setting of this dial is only required when the MICROMHOS switch is set to the SCALE "A" SHUNT position.
(6) SCALE: In this column are listed the proper settings for the MICROMHOS switch. The letters "A", "B", "C", "D", and "E" also correspond with the meter scale on which readings are to be taken.
(7) PRESS: Under this heading are listed the correct test PUSHBUTTONS to use for the various tube types and their individual sections in the case of multipurpose tubes.
(8) MUT. COND: In this column are the MINIMUM, not average, mutual conductance values for amplifier tubes and amplifier sections of multipurpose tubes. A lower mutual conductance reading generally indicates an unsatisfactory tube. Classes of tubes, or sections of multipurpose tubes other than amplifier having no mutual conductance rating are indicated in this column by the following designations:

Rect. . . . . . .Rectifier (power type)
Diode . . . . . .Detector type diode rectifier
Thyr . . . . . .Thyratron
Eye . . . . .Tuning Eye

(9) NOTATIONS: Under this heading is listed special information pertaining to particular tube types.

Line Voltage Test

During the following discussion of theory of operation refer to the simplified power supply circuit in figure 12-20.

Pressing the LINE ADJ. pushbutton P-1 connects the meter M101 in the bridge circuit associated with rectifier CR101 and through series, resistors R126 and R129 to the power transformer, T101 (fig. 12-20).

The value of the screw driver operated internal calibration resistor R126 is adjusted so that 121 volts RMS across 19 and 37 of the power supply will cause the meter M101 to read at LINE TEST (fig. 12-21).

The design of the power transformer T101 is such that 93 volts applied to the primary winding will induce 121 volts across the total secondary # 7 winding or across points 19 and 37.

Therefore, if with the LINE ADJ. pushbutton P-1 pressed down, the LINE ADJUST CONTROL R122 is turned until the pointer of the meter, M101, is exactly over the LINE TEST mark a standard voltage of 93 volts RMS will be established across the primary winding of T101.

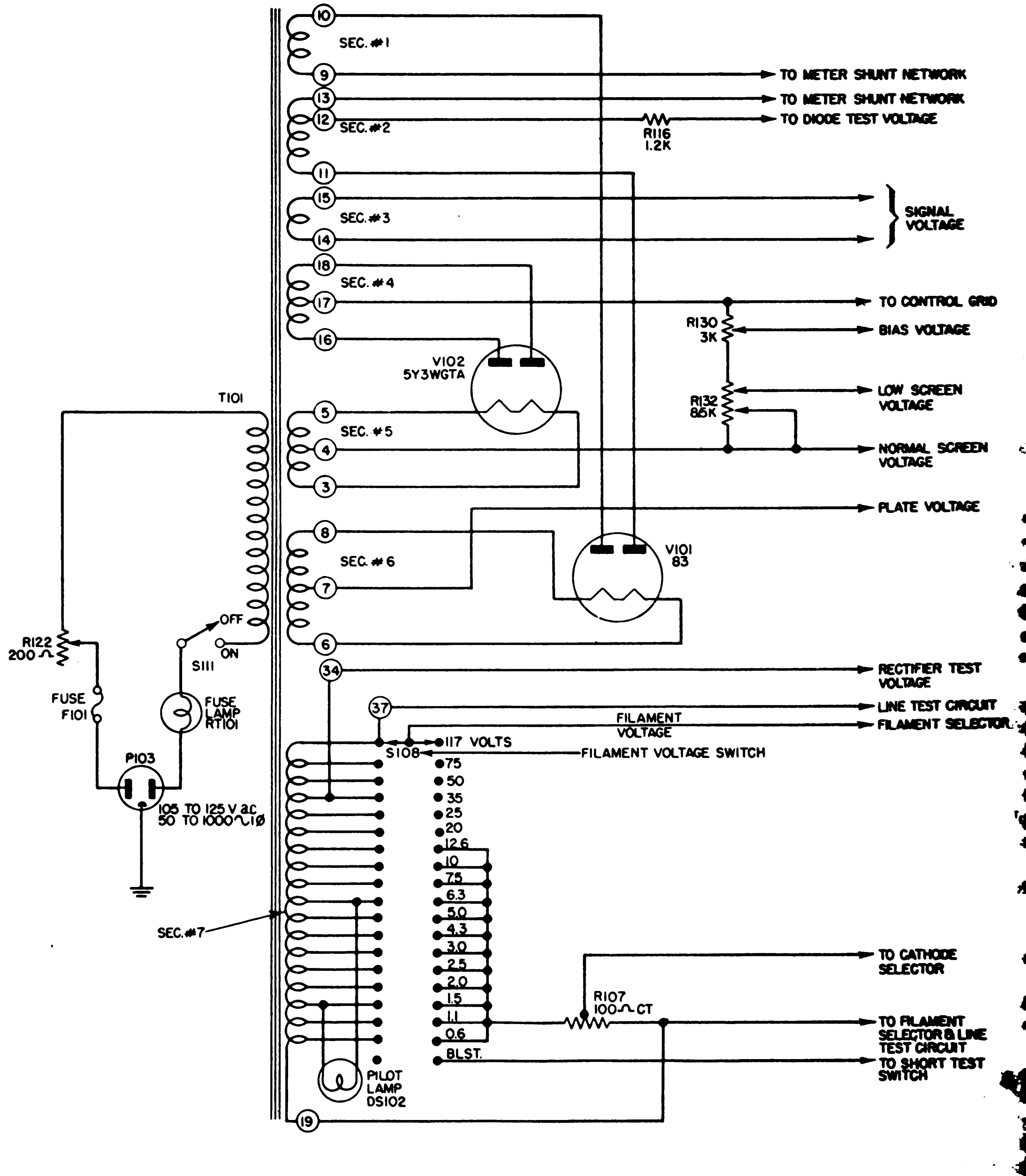

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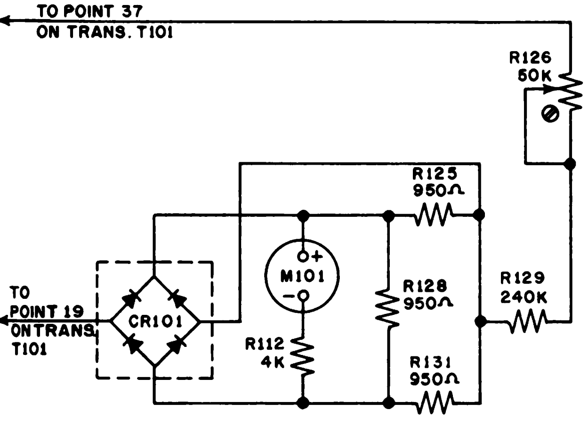
Figure 12-20.—Simplified power supply circuit.



167.789
gure 12-21.—Simplified line voltage test circuit.

ort Test

An a-c potential of approximately 170 volts MS from secondary # 2 of T101 is applied to ltage divider resistors R103 and R105 developg a voltage of approximately 90 volts RMS ross R103. This voltage is applied to the ements of the tube under test through the capator C102 and the neon short test lamp DS101 ich is shunted by R106 (fig. 12-22).

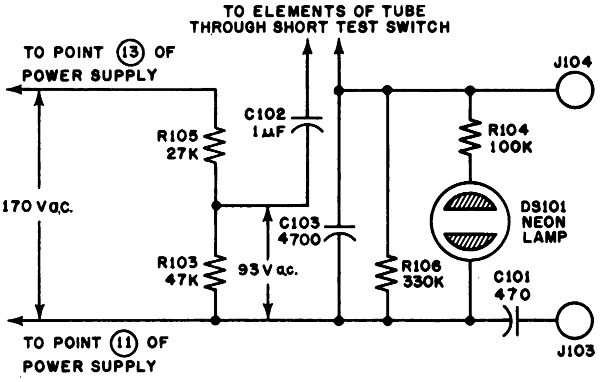
Turning the SHORTS test switch S109 through sition 1, 2, 3, 4, and 5 connects the various ements of the tube under test between the neon mp and capacitor C102. The SELECTORS must, course, be set correctly for the particular be. Any shorts between the elements will comete the circuit from capacitor C102 to the on lamp causing it to glow.

ise Test

The short test circuit may also be used for king a noise test of electron tubes.

Connect the NOISE TEST jacks, J103 and J104, the antenna and ground posts of any radio ceiver.

Turn the SHORTS test switch S109 through sitions 1, 2, 3, 4, and 5, meanwhile tapping tube under test with a finger, or the eraser a pencil. Intermittent disturbances between electrodes too brief to register on the neon mp will cause a momentary short, permitting alternating voltage from the power supply be applied to the neon lamp causing a brief oscillation. This oscillation will be reproduced by the loud speaker or headphones as an audible signal similar to static.



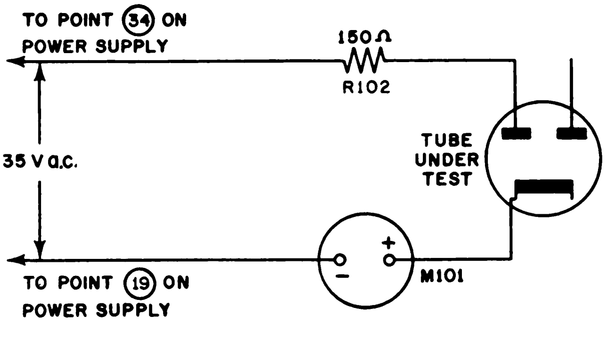
167.790
Figure 12-22.—Simplified short test circuit.

Rectifier Test

Rectifier tubes and diode detector tubes can only be tested for emission. The test circuit is therefore quite simple (fig. 12-23).

Pressing button P7 applies an a-c potential of 35 volts between the cathode and plate of the tube under test through resistor R102, and the meter, M101, causing the tube to rectify. This test is used for power rectifiers such as the 5Y3 or 83 types.

The rectifying action of the tube under test will cause a direct current to flow through the meter. Since the current indicated by the meter



167.791
Figure 12-23.—Simplified rectifier test circuit.

is proportional to the electron emission of the tube, the meter reading may be taken as a measure of the tube's efficiency.

A line on the meter scale marked RECTIFIER OK indicates the point above which rectifier tubes are considered satisfactory. Tubes reading below this line should be rejected.

Pressing the button P6 sets up a circuit similar to figure 2-6, but a higher voltage is applied, 330 volts a-c, for testing rectifiers of the cold cathode type such as the 0Z4.

Pressing button P2 also establishes a circuit similar to figure 2-6, but a lower voltage, 20 volts a-c, is used to protect the delicate cathodes of diode detector types such as the 6H6.

Mutual Conductance

The mutual conductance (gm) of an amplifier-type vacuum tube, also called the grid-plate transconductance, is an expression representing the efficiency of performance of a tube as indicated by the change in plate current (ΔIp) divided by the change in grid voltage (ΔEg). The relation is generally written Gm—ip/eg. The value is expressed in micromhos and is a performance indication because it shows how effective a tube is in converting a small change in grid voltage (grid signal) to a large change in plate current.

For the measurement of the mutual conductance value directly, the proper d-c grid voltage for the tube under test is supplied by a full-wave rectifier circuit using a 5Y3WGTA tube, V102. Setting BIAS control potentiometer R130 at the value called for on the test data roll chart adjusts this negative bias voltage to the correct value for the particular tube under test (fig. 12-24).

Alternating signal voltage from a separate secondary winding (Sec. # 3) on the power transformer, T101, acts in series with the grid bias as required for this type of test. This voltage alternately swings the grid in positive and negative directions from the d-c bias value, thereby producing the grid-voltage (ΔEg) required for a dynamic test.

The plate voltage for the tube under test is supplied by another full-wave rectifier circuit, using a type 83 tube V101. The return lead contains the meter circuit which serves to measure the plate-current change (ΔIp).

The mutual conductance test circuit is actuated by pushbutton P3.

The normal screen voltage of 130 volts is excessive for testing certain tubes such as type 1R5. In such cases it is necessary to pres pushbutton P2 before pressing the red pushbutto P3. Pressing P2 operates switch S110-2 an reduces the screen voltage to approximately 5 volts as illustrated by figure 12-24.

Gas Test

Pressing GAS-1 pushbutton P4 applies definit values of plate voltage and grid bias voltage t the tube under test, causing a definite value o plate current to flow. This current is indicate on the meter, M101 (fig. 12-25).

Pressing GAS-2 pushbutton P5 inserts 180,000 ohm resistor, R127, in the grid circuit If grid current is flowing from the bias voltag source through the grid circuit to the cathod due to gas in the tube, this current will develo a voltage drop across resistor R127. This voltag drop will reduce the negative bias on the grid causing a corresponding increase in the plat current being measured by the meter.

If the tube contains gas, the pointer of th meter will move up scale. This increase i meter reading should not exceed one scal dvision.

TRANSISTOR TESTING

Transistors may be tested "in-circuit" o "out-of-circuit." Also, the tests may be either d-c, where the measurements are made by d-c test equipment, or a-c, where there is an a-c input to the base circuit and an output from the collector circuit. A-c measurements may be mad either in-circuit or out-of-circuit only; otherwise, the measurements might be affected b equipment a-c or biasing voltages.

PRECAUTIONS TO TAKE BEFORE MAKING ANY TRANSISTOR TEST

1. Make sure that all power has been removed from the equipment under test before servicing testing, or removing a transistor or transistorized assembly.

2. Before employing any test equipment, i should first be determined that the test instrumen meets the requirements for the test and type o circuit.

3. Be sure that any line-powered test equipment has been properly grounded to the chassis the equipment under test.

4. Check the test equipment circuit on al ranges, to be sure that it does not pass mor than 1 milliampere of current through the tran istorized circuit under test. More amperag

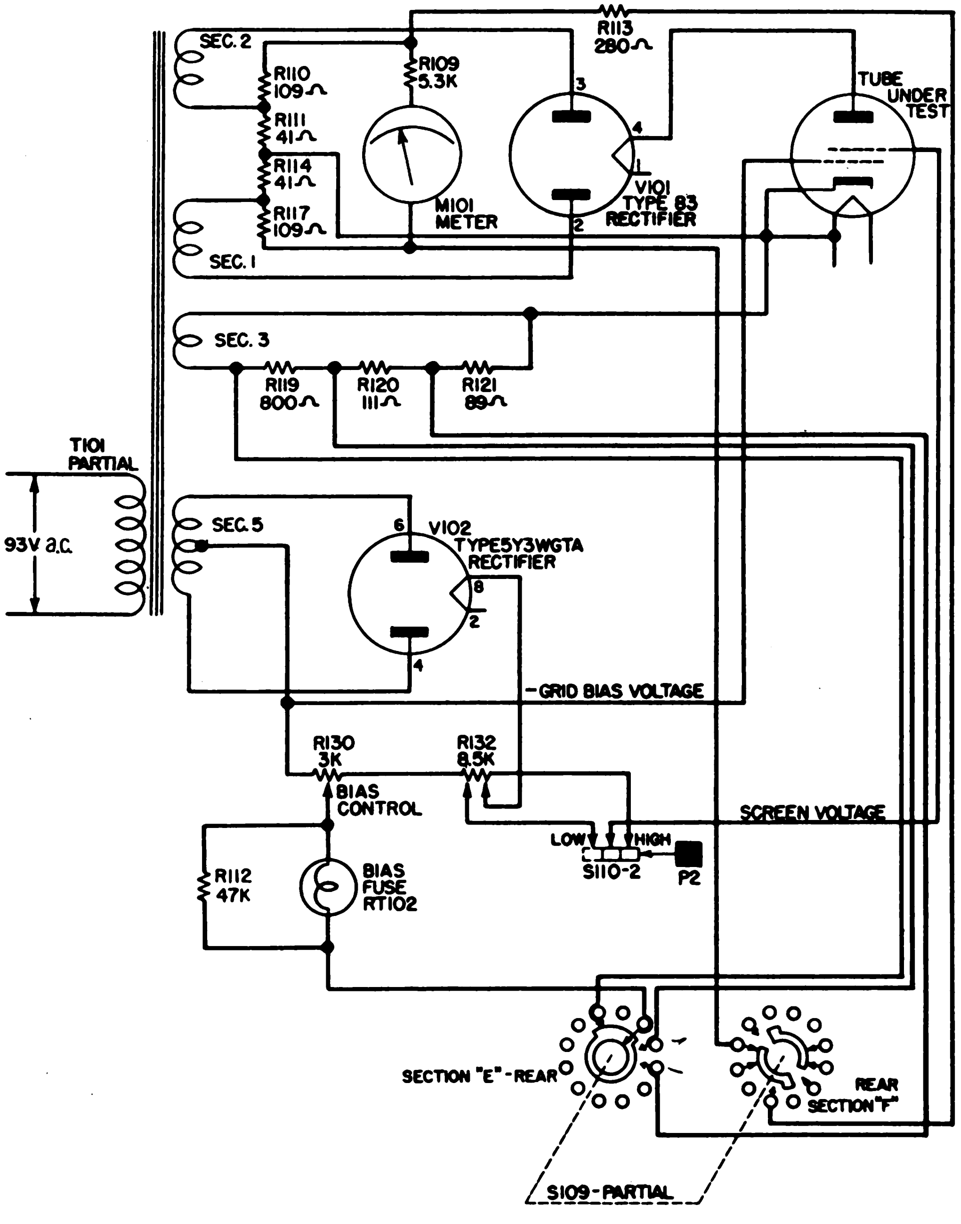


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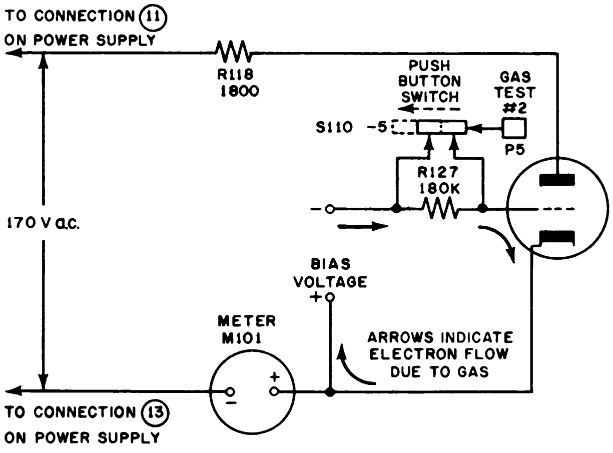
Figure 12-24.—Simplified mutual conductance test circuit.

annot safely be used for testing most transistor ircuits. Use a low-resistance milliammeter in eries with the test leads for this check (fig. 2-26).

5. Before making any measurements, be sure at any voltage applied is of the correct polarity r the circuit under test. Do not depend on the indicated polarity; use a voltmeter in series with the test leads for this check.

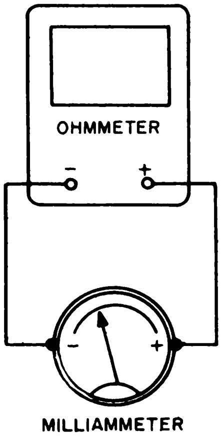
6. Do not troubleshoot transistor circuits by the shorting-to-ground method. Short circuits of any kind will damage a transistor. Extreme care must be taken to avoid these shorts—use



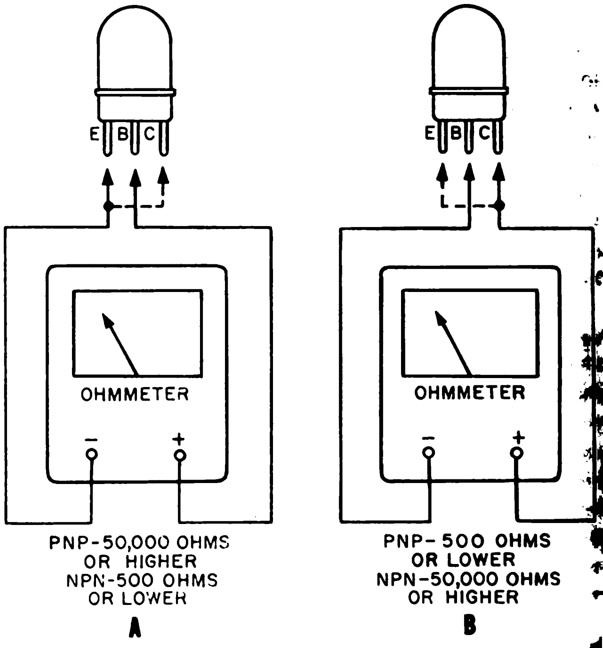
167.793
Figure 12-25.—Simplified gas test circuit.

special insulated test probes to prevent accidental shorting.

A rough check may be made on a transistor by means of d-c tests that will determine its forward and backward resistances and also any leakages or shorts. Connections for these tests are shown in figure 12-27. With the positive ohmmeter lead connected to the base of a PNP transistor (fig. 12-27A), a high-resistance reading (50,000 ohms or higher) should be obtained between base and emitter, and between base and collector. With the negative ohmmeter lead connected to the base of a PNP transistor (fig. 12-26B), the resistance between the base and collector and between the base and emitter should be 500 ohms or less. If the same ohmmeter tests are made on an NPN transistor, the results will be reversed; that is, the high-resistance readings will be obtained with the negative ohmmeter lead connected to the base, and the low-resistance readings with the positive ohmmeter lead connected to the base. If the correct resistance readings are not obtained from the ohmmeter test, the transistor should be replaced.



1.289
Figure 12-26.—Measuring current passed by ohmmeter.



1.2
Figure 12-27.—Transistor resistance testin
A. Base lead positive. B. Base lead negative.

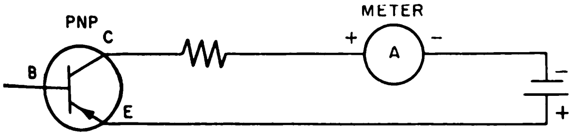
This type of test may also be used fo determining the type of a transistor, PNP o NPN, when its type is unknown. With the test connection as in figure 12-27A, a high-resistance reading (50,000 ohms or higher) shows that i is a PNP type; a low-resistance reading (5 ohms or less) shows that it is an NPN type.

In checking transistors, there are two basic sts—collector current leakage and transistor in, or amplification.

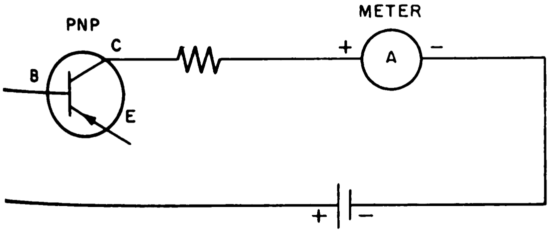
Age and exposure to higher-than-normal temratures may develop greater-than-normal colctor leakage current, generally designated as o. Such current is greatly dependent on ambient mperature; thus extreme care must be taken see that this temperature remains under conol. One positive sign of a defective transistor instability of I_{CO}. When there is a tendency r the leakage current to climb slowly of its vn accord, it is quite evident hat the transistor defective. A high leakage current indicates deterioration of the transistor, and is usually ccompanied by lower gain.

As illustrated in figure 12-28, collector leakge current tests may be made in two ways. igure 12-28A shows the connections for checking e leakage current in the collector-emitter ircuit, with the base open. Figure 12-28B ows the connections for checking the leakage urrent in the collector-base circuit, with the mitter open. Any contamination on the surface f the transistor, or a short circuit within, ill produce a high current reading on the eter.

In comparing the two test arrangements, e only advantage of the test in figure 12-28A is at, since the collector-emitter circuit is of w resistance (possible about 1000 ohms), norally there will be sufficient leakage current be read on a milliammeter, which is nearly always available. However, the test outlined in figure 12-28B requires a much more sensitive instrument, and is preferred if a suitable instrument is available. Since the transistor is reverse-biased (PNP-type transistor with negative terminal of battery toward collector), the reverse current is very small. It is a high-resistance circuit (on the order of 50,000 to 70,000 ohms), and the leakage current is usually no more than 10 to 15 microamperes. Such small currents are best measured on a transistor test set, which is usually provided with a sensitive microammeter.



A COLLECTOR-EMITTER LEAKAGE TEST



B COLLECTOR-BASE LEAKAGE TEST

70.103

gure 12-28.—Collector leakage current test, schematic diagram.

TEST FOR BETA

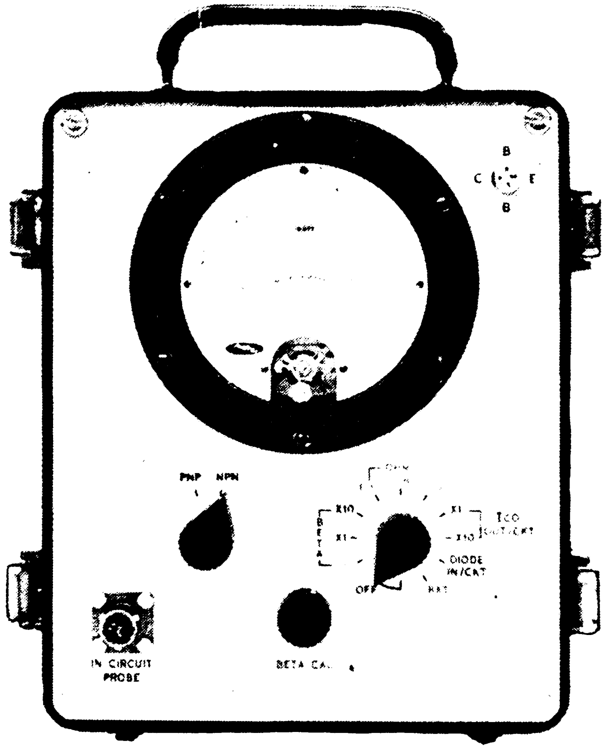
Since one of the primary functions of a junction transistor is amplification, one of the basic tests, in addition to the collector leakage test, is a check of gain (or amplification), referred to as "beta." The gain test is a measurement of the change in collector current for a small change in the base current.

All of the current in a transistor is supplied by the emitter, of which more than 90 percent goes to the collector and the remainder to the base. Where, for example, 95 percent of the current goes to the collector and 5 percent to the base, then beta = 95/5 = 19. A beta of 19, then, means that for any change in current in the base, the change in the collector will be 19 times as great.

To measure beta, approximately correct results can be obtained by removing the transistor from the equipment and using d-c test methods. Better results can be obtained, however, when the test is made under operating conditions, using a-c test methods. This test can best be accomplished by use of a transistor test set designed specifically for the purpose.

TEST SET AN/USM-206

Transistor Test Set AN/USM-206 (fig. 12-29) is a portable instrument used for troubleshooting semiconductor circuits. It has been designed to preclude the possibility of externally induced or "self-made" failures by limiting the power that can be applied to the circuits under test. Accordingly, damage cannot occur to the semiconductor under test from the application of incorrect polarity. The test set measures the Beta of a transistor, the resistance appearing at the electrodes of a transistor or diode, the reverse leakage of a transistor or diode, a



26.237
Figure 12-29.—Test set, Semiconductor Device AN/USM-206 (cover removed).

shorted or open condition of a diode, and the condition of its own batteries. The Transistor Characteristics Data Book, NAVSHIPS 0969-002-9020, should be used for comparing the measured characteristic with the characteristic value of a good transistor.

The test set operating instructions and equivalent circuits are shown in figure 12-30.

Figure 12-31 is a simplified schematic of the AN/USM-206 Test Set.

CATHODE-RAY OSCILLOSCOPE

The cathode-ray oscilloscope is one of the most useful and versatile of test instruments. It is essentially a device for displaying graphs of rapidly changing voltages or currents, but is also capable of giving information concerning frequency values, phase differences, and voltage amplitude. It is used to trace signals through electronic circuits to localize sources of distortion and to isolate troubles to particular stages. An oscilloscope that the FTM is likely to use is the Tektronix Type 545B.

THE TEKTRONIX TYPE 545B OSCILLOSCOPE

The Tektronix Type 545B Oscilloscope (fig 12-32) is a dual trace laboratory type oscilloscope. While the 545B was primarily designe for commercial use, it is rugged enough fo military use, including shipboard operation.

The following brief discussion covers th characteriestics and operation of the 545B. Fo more complete details, refer to the appropriat technical manuals.

The Type 545B Oscilloscope features tw time base generators, and was designed fo use with all Tektronix letters or 1-series plug in units.

The two time base generators can be use in delayed sweep operation for highly accurat time measurements.

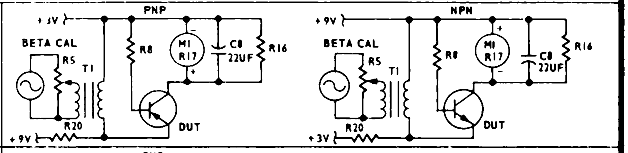
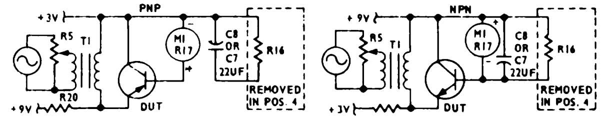
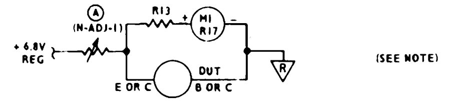
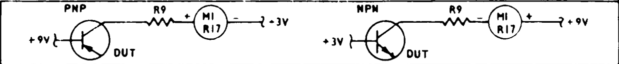
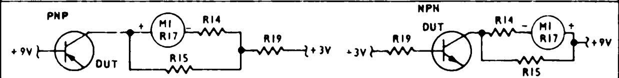
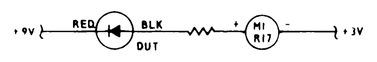
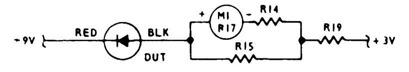
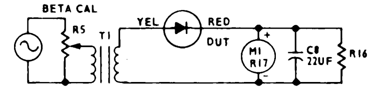
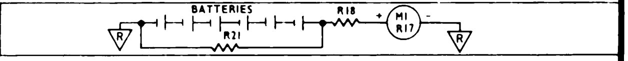
Function of Controls and Connectors

The Time Base A and Time Base B control serve identical functions with the exception the LENGTH control.

TRIGGERING LEVEL	Selects the amplitude point o the triggering signal wher sweep-triggering occurs.
STABILITY	Adjusts the oscilloscope fo a stable displayed waveform The STABILITY control ca be set to the PRESET positio and left there. This positio provides for convenient triggering since only the TRIGGERING LEVEL control need to be adjusted to obtain a stable display.
TRIGGERING MODE	AUTO: Permits normal triggering on signals with repetition rates higher than abou 50 Hz. With no trigger signal or with a lower repetitio rate, the trigger circuit fre runs at approximately 40 H and triggers the time base a this rate, providing a reference trace.

CAUTION: DEENERGIZE EQUIPMENT BEFORE PERFORMING IN-CIRCUIT TESTS

OPERATING INSTRUCTIONS

S2 PNP NPN SWITCH	S1 FUNCTION	POS	ACTIONS AND INDICATIONS	EQUIVALENT CIRCUITS
—	OFF	1	METER POINTER INDICATES EXACTLY ZERO Ⓐ WHEN METER IS NOT IN USE, S1 SHOULD ALWAYS BE 'OFF' TO AVOID UNNECESSARY DRAIN ON METER BATTERIES.	
BETA MEASUREMENTS (IN OUT OF CIRCUIT)				
CORRESPONDS TO TYPE OF DEVICE UNDER TEST (DUT)	BETA CAL	2	PLUG TRANSISTOR IN TEST JACK, CBE (TRANSISTOR SOCKET J2); OR CONNECT TEST LEADS TO TRANSISTOR WITH YELLOW TO EMITTER, BLACK TO BASE AND RED TO COLLECTOR. ADJUST 'BETA CAL' CONTROL R5, SO THAT METER INDICATES FULL SCALE.	 PNP +3V BETA CAL R5 T1 R8 M1 R17 C8 22UF R16 DUT R20 +9V NPN +9V BETA CAL R5 T1 R8 M1 R17 C8 22UF R16 DUT R20 +3V
	BETA X1	3	METER INDICATES BETA DIRECTLY ON TOP SCALE. IF METER INDICATES BETA IS GREATER THAN 10, PLACE FUNCTION SWITCH S1 IN THE 'BETA X 10' POSITION. (SEE NOTE)	 PNP +3V R5 T1 M1 R17 C8 OR C7 22UF R16 REMOVED IN POS. 4 DUT R20 +9V NPN +9V R5 T1 M1 R17 C8 OR C7 22UF R16 REMOVED IN POS. 4 DUT +3V
	BETA X 10	4	MULTIPLY THE METER INDICATION OF BETA BY 10 TO OBTAIN BETA (SEE NOTE)	
ELECTRODE RESISTANCE MEASUREMENTS (IN CIRCUIT)				
—	OHMS E-B	5	CONNECT TEST LEADS TO TRANSISTOR - IN CIRCUIT - WITH YELLOW TO EMITTER, BLACK TO BASE, AND RED TO COLLECTOR. RESISTANCE APPEARING BETWEEN EMITTER AND BASE ELECTRODES IS INDICATED ON THE CENTER (RED) SCALE OF THE METER.	 Ⓐ (N-ADJ-1) R13 M1 R17 +6.8V REG DUT E OR C B OR C R (SEE NOTE)
	OHMS C-B	6	RESISTANCE APPEARING BETWEEN COLLECTOR AND BASE ELECTRODES IS INDICATED ON THE CENTER (RED) SCALE OF THE METER.	
	OHMS C-E	7	RESISTANCE APPEARING BETWEEN COLLECTOR AND EMITTER ELECTRODES IS INDICATED ON THE CENTER (RED) SCALE OF THE METER.	
Ico MEASUREMENTS (OUT OF CIRCUIT)				
CORRESPONDS TO TYPE OF DEVICE UNDER TEST (DUT)	Ico OUT/CKT X1	8	PLUG TRANSISTOR IN TEST JACK, J2. METER INDICATES Ico DIRECTLY IN MICROAMPERES ON LOWEST SCALE. IF METER INDICATES OFF SCALE, PLACE FUNCTION SWITCH, S1, IN THE X10 POSITION.	 PNP +9V DUT R9 M1 R17 -3V NPN +3V DUT R9 M1 R17 +9V
	Ico OUT/CKT X10	9	MULTIPLY THE METER INDICATION OF Ico BY 10 TO OBTAIN Ico IF METER INDICATES OFF SCALE. REVERSE PNP/NPN SWITCH AND REPEAT POS. 8 TEST	 PNP +9V DUT M1 R17 R14 R19 R15 +3V NPN DUT R14 M1 R17 +9V R19 +3V R15
DIODE Ir MEASUREMENTS (OUT OF CIRCUIT)				
PNP	Ico OUT/CKT X1	8	CONNECT CATHODE OF DIODE TO RED TEST LEAD, AND ANODE OF DIODE TO BLACK TEST LEAD. METER INDICATES Ir DIRECTLY IN MICROAMPERES ON LOWEST SCALE. IF METER INDICATES OFF SCALE, PLACE FUNCTION SWITCH, S1, IN THE X10 POSITION.	
	Ico OUT/CKT X10	9	MULTIPLY THE METER INDICATION OF Ir BY 10 TO OBTAIN Ir. IF METER INDICATES OFF SCALE, REVERSE PNP NPN SWITCH AND REPEAT POS 8 TEST.	 -9V RED BLK DUT M1 R17 R14 R15 R19 +3V
DIODE IN CIRCUIT MEASUREMENTS				
PNP	DIODE IN/CKT	10	CONNECT CATHODE OF DIODE TO RED TEST LEAD, AND ANODE OF DIODE TO YELLOW TEST LEAD. INCREASE 'BETA CAL' CONTROL UNTIL METER DEFLECTS UPSCALE. REVERSE PNP NPN SWITCH IF METER DEFLECTS DOWNSCALE. NO DEFLECTION OF METER INDICATES THAT THE DIODE IS EITHER OPENED OR SHORTED, OR THAT THE RELATED CIRCUIT IMPEDANCE IS LESS THAN 20 OHMS.	 BETA CAL R5 T1 YEL RED DUT M1 R17 C8 22UF R16
BATTERY CHECK				
—	BAT	11	IF BATTERIES ARE GOOD, METER INDICATES IN THE RED BOX LABELED 'BAT'.	

Ⓐ · ALIGNMENT PROCEDURE

NOTE: POSITIONS 5, 6, AND 7 ARE USED TO PRECLUDE FALSE INTERPRETATIONS OF IN-CIRCUIT BETA MEASUREMENTS, SINCE ACCURACY OF THE BETA X 1 RANGE IS ±10% ONLY WHEN E TO B LOADING IS EQUAL TO OR GREATER THAN 50 OHMS; BETA X 10 IS ±10% ONLY WHEN E TO B LOADING IS EQUAL TO OR GREATER THAN 500 OHMS.

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Figure 12-30.—Operating instructions for AN/USM-206.

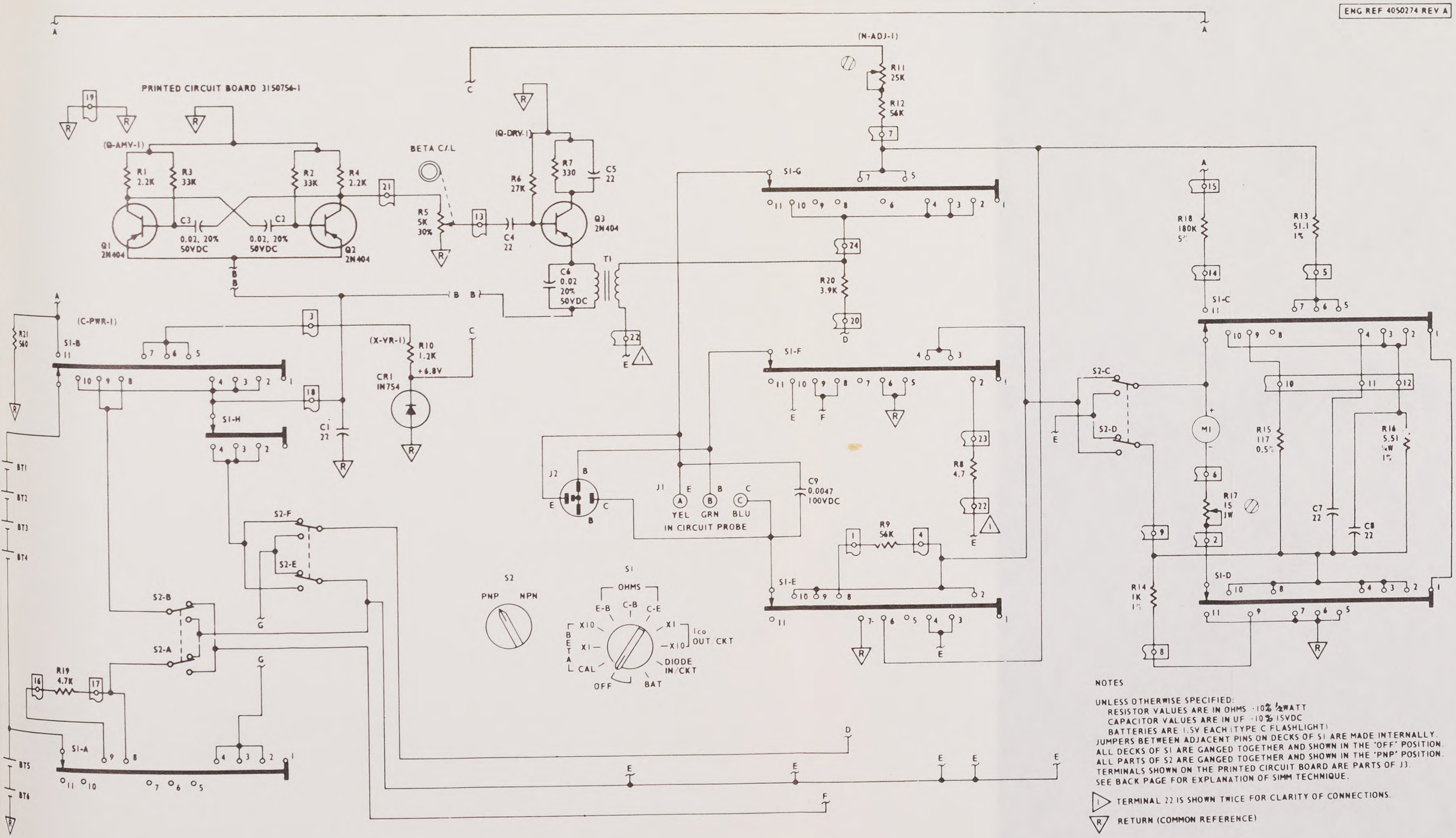
AC LF REJ: Attenuates trigger-signal frequencies below about 17 kHz allowing the trigger circuit to respond only to higher frequencies.

AC: Blocks the d-c component of the triggering signal and allows triggering to take place only on the changing portion of the signal.

For frequencies below about 30 Hz, use the DC position.

For best triggering at high frequencies, use an a-c coupling position of the TRIGGERING MODE switch.

	DC: Permits triggering on both high- and low-frequency (to d-c) signals.
TRIGGER SLOPE	Determines whether the time base is triggered on the negative- (-) or positive- (+) going slope of the signal.
	LINE: Uses a line-frequency signal as a trigger.
	INT: Uses a portion of the signal applied to the vertical deflection plates of the CRT as a trigger signal.
	EXT: Provides external triggering on a signal applied to the TRIGGER INPUT connector.
TIME/CM	Selects the time-base sweep rate.
TIME/CM VARIABLE (Time Base A)	Provides an uncalibrated sweep rate adjustment. The sweep rate can be slowed to at least 0.4 X any setting of the TIME/CM switch. An UNCALIBRATED lamp lights when the VARIABLE control is not in the CALIBRATED position.
LENGTH (Time Base B)	Controls the length of the B sweep.
HORIZONTAL DISPLAY	A: Allows only Time Base A to display on the CRT.
	B: Allows only Time Base B to display on the CRT.
	'B' INTENSIFIED BY 'A': One of the delayed-sweep functions. In this position, a portion of Time Base B is intensified during the time that Time Base A (the delayed sweep) is in operation.
	'A' DLY'D BY 'B': One of the delayed sweep functions. In this position, Time Base A is displayed at the end of each delay period as determined by the B TIME/CM OR DELAY TIME and DELAY-TIME MULTIPLIER controls.
	'A' SINGLE SWEEP: Allows the Time Base A generator to sweep once upon receipt of trigger signal and not sweep again until the circuit has been reset with the RESET button. Single sweep permits photographing nonrepetitive waveforms, which otherwise would not be photographed clearly.
	EXT X1 and X10: Permit an external signal to be applied to the horizontal deflection circuit. Sensitivity is continuously variable (with the VARIABLE 10-1 control).
5X MAGNIFIER	Expands the sweep from the center of the graticule at any setting of the TIME/CM switch by 5 times.
DELAY-TIME MULTIPLIER 1-10	Works in conjunction with the Time Base B TIME/CM OR DELAY TIME switch.
	Varies sweep delay from 0 to 10 times the rate indicated by the Time Base B TIME/CM OR DELAY TIME switch.
AMPLITUDE CALIBRATOR	Determines the peak-to-peak voltage available at the CAL OUT connector.
Beam Position	Four neon lamps (above the CRT) with accompanying arrows indicate the direction when the display is deflected out of the viewing area.
TRIGGER INPUT (Time Base A and B)	Connector for applying an external trigger signal to the time base when its TRIGGER SLOPE switch is set to the EXT position.



NOTES

UNLESS OTHERWISE SPECIFIED:
RESISTOR VALUES ARE IN OHMS ±10% ½WATT
CAPACITOR VALUES ARE IN UF ±10% 15VDC
BATTERIES ARE 1.5V EACH (TYPE C FLASHLIGHT)
JUMPERS BETWEEN ADJACENT PINS ON DECKS OF S1 ARE MADE INTERNALLY.
ALL DECKS OF S1 ARE GANGED TOGETHER AND SHOWN IN THE 'OFF' POSITION.
ALL PARTS OF S2 ARE GANGED TOGETHER AND SHOWN IN THE 'PNP' POSITION.
TERMINALS SHOWN ON THE PRINTED CIRCUIT BOARD ARE PARTS OF J3.
SEE BACK PAGE FOR EXPLANATION OF SIMM TECHNIQUE.

1 TERMINAL 22 IS SHOWN TWICE FOR CLARITY OF CONNECTIONS.

R RETURN (COMMON REFERENCE)

26.237

Figure 12-31. — Simplified schematic of AN/USM-206.

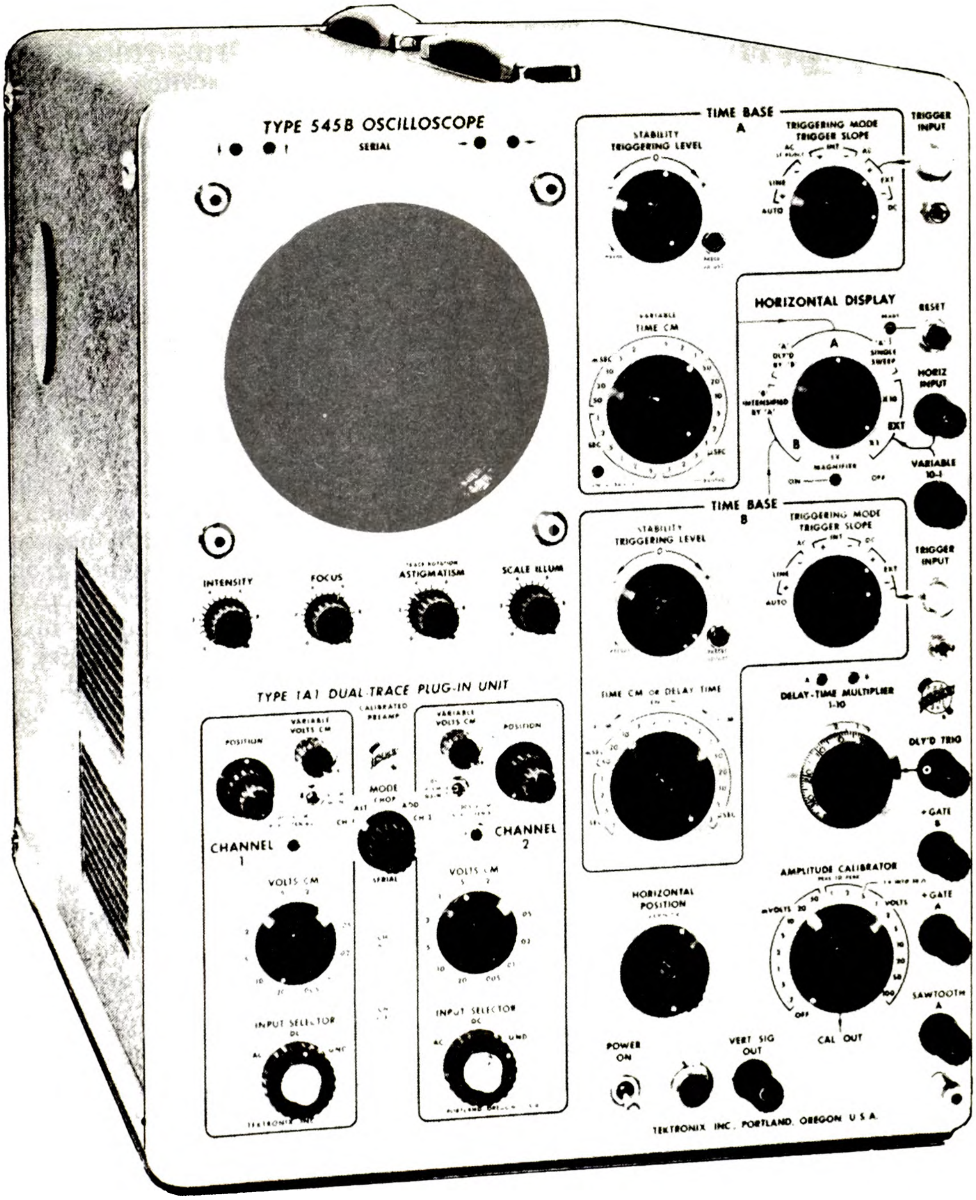


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Figure 12-32.—The Tektronix type 545B Oscilloscope.

HORIZ INPUT	Jack for applying external horizontal signal when the HORIZONTAL DISPLAY switch is set to either X1 or X10 EXT.
+GATE B	Supplies approximately a 20-volt squarewave pulse when Time Base B is operating. Pulse duration is approximately 10.5 X the setting of the TIME/CM OR DELAY TIME switch.
DLY'D TRIG	Supplies a sharp positive-going trigger spike of about

	5 volts at the end of the delay period as set by the TIME/CM OR DELAY TIME switch and the DELAY-TIME MULTIPLIER dial.
TOOTH A	Supplies the sawtooth voltage of Time Base A. Peak amplitude is about +130 volts.
TE A	Same as +GATE B except applies to TIME BASE A.
T SIG UT	Vertical signal output connector. Output amplitude is approximately 1.2 volts/cm of deflection.
CATHODE ELECTOR rear panel)	Provides blanking of between-channel switching transients (in the CHOPPED BLANKING positions) when using multi-channel plug-in units in the chopped mode. The CRT CATHODE SELECTOR switch should always be in the EXTERNAL CRT CATHODE position except when using the chopped mode.
ERNAL RT ATHODE	With the ground strap disconnected, this connector applies Z-axis modulation signals to the CRT cathode. The Z-axis signals should be at least 20 volts in amplitude to cause intensity modulation. Always have the ground strap connected except when applying Z-axis modulation signals.

nal (Nondelayed) Sweep

he Type 545B Oscilloscope features two
pendent time-base circuits: Time Base A
Time Base B.

WEEP TRIGGERING.—Proper sweep trig-
ng is essential for a stable presentation of
nput signal. For a stable display, the sweep
t be triggered at the same time relative
he displayed signal. Thus, the sweep must
riggered by the input signal or by some
rnal signal that has a fixed time relationship
the displayed signal. The external trigger signal must be the same frequency or a submultiple of the input signal.

SELECTING THE TRIGGER SOURCE.—The TRIGGER SLOPE switch selects one of a variety of possible triggering signals. For most applications, the sweep can be triggered internally from the displayed signal. This occurs with the TRIGGER SLOPE switch set at either + or - INT.

The LINE positions of the TRIGGER SLOPE switch connect a line-frequency signal to the triggering input. Line triggering is useful whenever the input signal is frequency-related to the line signal.

To trigger the time base from an external signal, set the TRIGGER SLOPE switch to an EXT position and connect the trigger signal to the TRIGGER INPUT connector. External triggering is often used when signal tracing in amplifiers, phase-shift networks, and waveshaping circuits. The signal from a single point in the circuit can be used as an external trigger signal. With this arrangement, it is possible to observe the polarity, shaping and/or amplification of a signal at various points in the circuit without resetting the triggering controls for each new display.

SELECTING TRIGGERING MODE.—Four means of trigger coupling are available with the TRIGGERING MODE switch. The different coupling positions permit you to accept or reject certain frequency components of the triggering signal.

With the switch set at DC, the time base can be triggered with all frequency components of the triggering signal within the trigger amplifier bandpass, including d-c levels.

With the switch set at AC LF REJ, d-c and low-frequency signals (below about 17 kHz) are rejected or attenuated. Thus, the trigger circuit will respond best to the higher-frequency components of the triggering signal.

With the switch set to AUTO, proper triggering automatically takes place. When the triggering signal is removed, the time-base circuit free runs and presents a reference display.

In general, use AC coupling. However, it will be necessary to use DC coupling for very low-frequency signals. When line-frequency hum is mixed with the triggering signal, it is best to use AC LF REJ coupling so that triggering takes place only on the signal of interest (if the signal of interest contains frequency components above about 17 kHz).

The AC LF REJ position is also useful when triggering internally from multichannel plug-in units operated in the alternate dual-trace mode. AC LF REJ coupling has a faster recovery time when subjected to the alternate d-c levels from the multichannel plug-in unit.

SELECTING TRIGGER SLOPE.—The TRIGGER SLOPE switch determines whether the triggering circuit responds on the rising (+ setting) or the falling (- setting) portion of the triggering signal. When several cycles of a signal appear in the display, the setting of the TRIGGER SLOPE switch will probably be unimportant. However, if you wish to look at only a certain portion of a cycle, the TRIGGER SLOPE switch will help start the display on the desired slope of the input signal. Figure 12-33 illustrates the effect of both the TRIGGER SLOPE and TRIGGERING LEVEL controls.

SETTING STABILITY CONTROL.—In nearly all triggering applications, satisfactory operation can be obtained with the STABILITY control in the PRESET (fully counterclockwise) position. The PRESET position has the advantage of requiring no further adjustment of the STABILITY control when switching from one triggering signal to another. However, if stable triggering becomes difficult with the STABILITY control at PRESET, it will be necessary to adjust the control for proper triggering. To adjust the STABILITY control, place the TRIGGERING LEVEL control in the fully counterclockwise position, then turn the STABILITY control slowly clockwise until a trace appears on the CRT. The correct setting is obtained by turning the control counterclockwise three to five degrees from the point where the trace appears.

SETTING TRIGGERING LEVEL.—The TRIGGERING LEVEL control determines the amplitude point on the signal where triggering occurs.

The trigger circuit is most sensitive to a-c triggering signals with the TRIGGERING LEVEL control set near zero. Moving the TRIGGERING LEVEL control in the + direction causes the trigger circuit to respond at some higher positive amplitude on the triggering signal. Moving the TRIGGERING LEVEL control in the — direction causes the trigger circuit to respond at some higher negative amplitude on the triggering signal.

SELECTING TIME/CM (SWEEP RATE).—The TIME/CM and 5X MAGNIFIER switches control sweep rate. The 5X MAGNIFIER switch expands both time bases.

The TIME/CM and 5X MAGNIFIER switches allow you to view an applied signal at a wide variety of calibrated sweep rates. When making time measurements from the CRT, be sure the VARIABLE control is set to CALIBRATED (time base A).

When the 5X MAGNIFIER switch is set to OFF, the TIME/CM switch indicates the true sweep rate. However, with the 5X MAGNIFIER switch set to ON, the setting of the TIME/CM switch must be divided by 5 to determine the true sweep rate. For example, assume that the TIME/CM switch is set at 1 msec and the 5X MAGNIFIER is set to ON. In this case, the true sweep rate would be 1 msec divided by 5 (5X MAGNIFIER setting); resulting in a displayed sweep rate of 0.2 msec/div. Figure 12-34 illustrates how to make time measurements from the graticule.

SINGLE-SWEEP OPERATION.—In applications where the displayed signal is not repetitive or varies in amplitude, shape, or time, a photograph of a conventional repetitive display may produce a jumbled presentation. To avoid this, use the single-sweep feature of the Type 545B to photograph this type of display. To use single sweep, first make sure the trigger circuit will trigger on the event you wish to display. Do this in the conventional manner with the HORIZONTAL DISPLAY switch set to either time base. Then, after setting the HORIZONTAL DISPLAY switch to "A" SINGLE SWEEP, press the RESET switch and release. When this is completed, the next trigger pulse will actuate the sweep and the Type 545B will display the event on a single trace. The READY lamp, near the HORIZONTAL DISPLAY switch, first lights when the sweep is ready to accept a trigger and then goes out after triggering has taken place. To ready the circuit for another single display, press the RESET switch and release. In single-sweep operation, make sure the TRIGGER MODE switch is not set to AUTO.

Nontriggered Delayed Sweep

The following procedures describe various measurements, the accuracy of those measurements, and other operations that can be performed using delayed sweep.

Insert a vertical plug-in unit and set the controls and switches on the instruments as listed in Table 12-1.

Set the HORIZONTAL POSITION control so the trace begins precisely at the left-hand edge

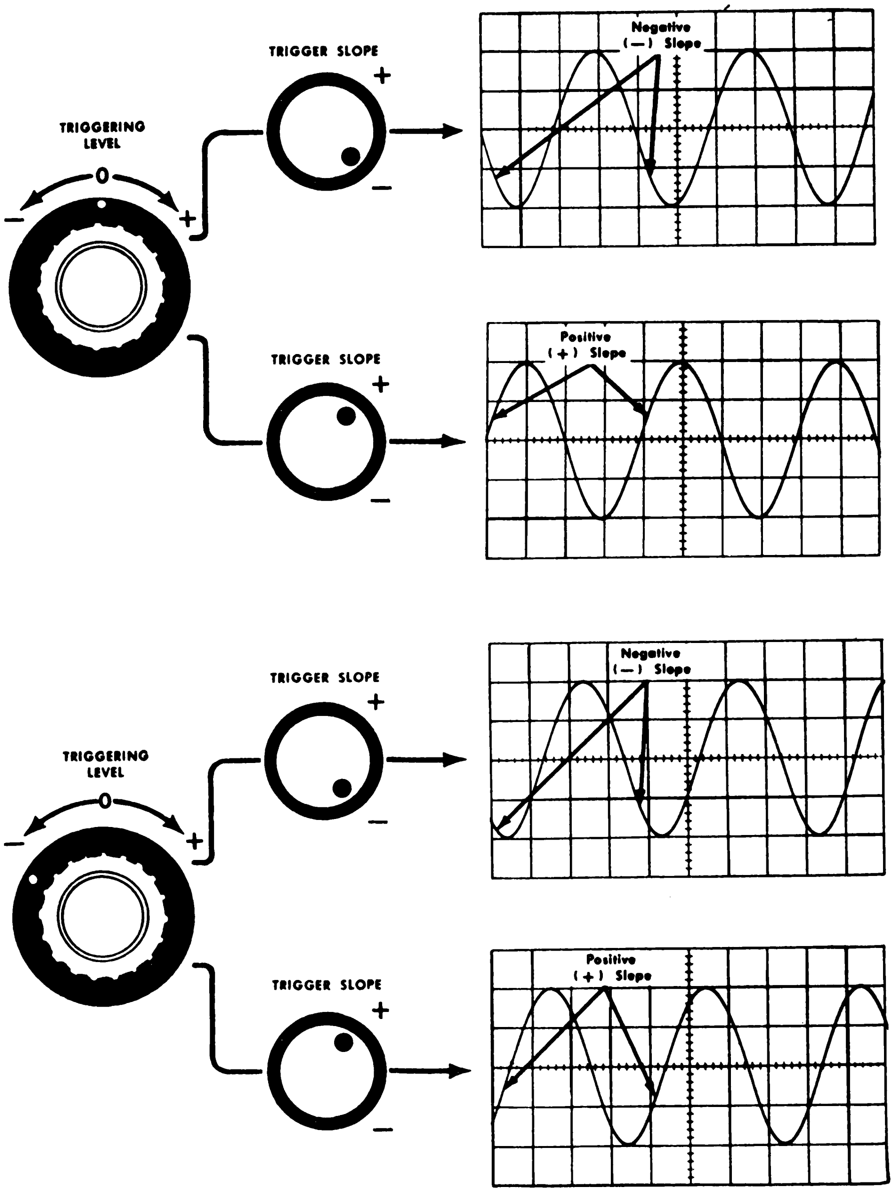

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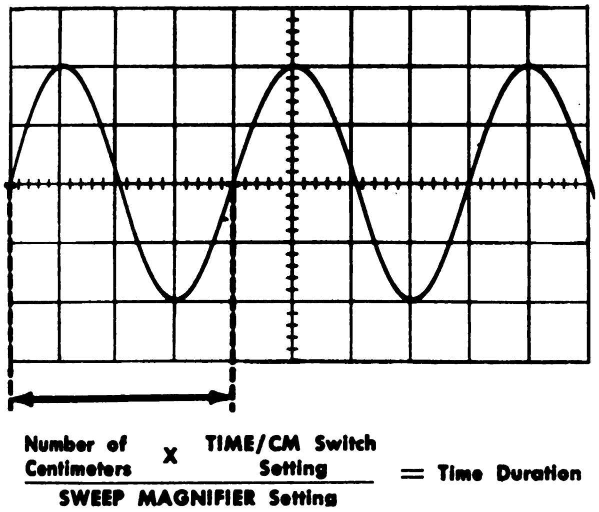
Figure 12-33.—Effects on oscilloscope display produced by + and - settings of the TRIGGERING LEVEL control.


Number of Centimeters X TIME/CM Switch Setting / SWEEP MAGNIFIER Setting = Time Duration

151.268
Figure 12-34.—Time measurement from the graticule.

of the graticule. Notice the position of the intensified segment in the trace.

Now set the TIME/CM or DELAY TIME switch to 0.2 sec and A TIME/CM switch to 20 μsec. The intensified segment should be at the same position as with the previous sweep rates.

Connect the SAWTOOTH A output to the vertical plug-in unit input. Notice that the A sweep sawtooth and the intensified segment in the trace start and end at the same time. This display shows that time base A produces one sweep during the intensified segment of each B sweep. The A TRIGGERING LEVEL control has no effect.

The B sweep rate is 0.2 sec/cm. The intensified segment begins 5 cm after the beginning of the trace. Hence, the A sweep starts 1 sec after the B sweep (0.2 sec/cm X 5 cm).

The number of centimeters between the beginning of the trace and the beginning of the intensified segment is established by the setting of the DELAY-TIME MULTIPLIER dial. Therefore, with any dial setting, the time difference between the beginning of the A and B sweeps is the product of the TIME/CM OR DELAY TIME switch and the DELAY-TIME MULTIPLIER dial setting (fig. 12-35).

Using nontriggered delayed sweep, the following measurements may be made.

1. Pulse duration with an accuracy to within 1% (±2 minor divisions) of the reading on the Delay-Time Multiplier Dial.

2. Time between pulses. The basic accuracy for this measurement is the same as for pulse duration. However, an error is introduced by the sweep-delay system linearity. This error is on the order of ±2 minor dial divisions; thus, the percentage of error decreases as the separation

Table 12-1.—Control settings when using delayed sweep

B TRIGGERING MODE	AC
B TRIGGER SLOPE	+ INT
B TRIGGERING LEVEL	0
B STABILITY	Fully clockwise
B TIME/CM OR DELAY TIME	1mSEC
B LENGTH	Fully clockwise
A TRIGGERING MODE	AC
A TRIGGER SLOPE	+ EXT
A TRIGGERING LEVEL	0
A STABILITY	Fully clockwise
A TIME/CM	1mSEC
VARIABLE	CALIBRATED
HORIZONTAL DISPLAY	'B' INTENSIFIED BY 'A'
SWEEP MAGNIFIER	OFF
DELAY-TIME MULTIPLIER	5.00
AMPLITUDE CALIBRATOR	10 Volts
HORIZONTAL POSITION	Centered
INTENSITY	So both intensity levels in the trace are easily seen.

Set the applicable controls and switches of the vertical plug-in unit as follows:

Volts/Div	5
Variable	Calibrated
AC-DC-Grnd	DC
Position	Trace centered

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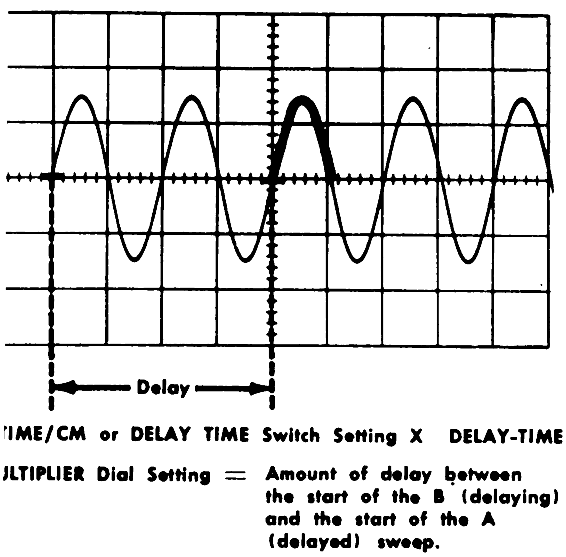
Delay
'IME/CM or DELAY TIME Switch Setting X DELAY-TIME
JLTIPLIER Dial Setting = Amount of delay between the start of the B (delaying) and the start of the A (delayed) sweep.

151.269
Figure 12-35.—Determining delay time.

een the initial and final dial settings in-
ses.
'or detailed procedures for making these
other measurements refer to the instructions
ıal for this oscilloscope.

gered Delayed Sweep

omplex signals contain a number of individual
ts at different amplitudes. Since the trigger
uits in the Type 545B respond to signal
itude, a stable display will normally be
ned only when the sweep is triggered by
vent having the greatest amplitude.
'he following instructions demonstrate that
e Base A can be triggered by any event
n a series of events, regardless of relative
itude.
et the controls and switches on the instrument
sted in Table 12-1.
'onnect the AMPLITUDE CALIBRATOR signal
he vertical input. Using the B triggering
rols, obtain a stable display.
'urn the DELAY-TIME MULTIPLIER dial
t two turns in either direction. Notice that
brightened segment in the display moves
othly across the CRT.
et the DELAY-TIME MULTIPLIER dial so
brightened segment begins about in the
middle of a pulse top. Now turn the HORIZONTAL DISPLAY switch to A and the TRIGGER SLOPE switch to +INT. Using the A triggering controls, obtain a stable display. Return the HORIZONTAL DISPLAY switch to 'B' INTENSIFIED BY 'A'. Notice that the brightened segment in the display has shifted to the next pulse on the right. (If the brightened segment is not present, or is unstable, readjust the A triggering controls) Turn the DELAY-TIME MULTIPLIER dial several full turns. The brightened segment in the display should jump from one pulse to the next. Set the HORIZONTAL DISPLAY switch to 'A' DLY'D BY 'B' and note that the display now begins on the rising portion of the pulse. With the present display, turning the DELAY-TIME MULTIPLIER dial should not change the display since all of the AMPLITUDE CALIBRATOR pulses are the same shape. However, if the input signal consists of a repeating series of several dissimilar pulses, turning the dial would provide a triggered display of each pulse in the series provided the A triggering controls are set for triggering on the smallest pulse.

The display is produced in the following manner:

Time Base A produces one sweep during each B sweep. The Time Base A sweep will begin some time after the start of B sweep. This time is the total of the TIME/CM OR DELAY TIME switch setting multiplied by the DELAY-TIME MULTIPLIER dial setting, plus the time between the end of this delay interval and the next event in the signal which can trigger Time Base B.

With the A triggering control set for triggered operation, the Time Base A sweep will occur only if A is armed and triggered before the B sweep ends. If Time Base A is not triggered, the scope waits.

External Horizontal Deflection

For special applications, horizontal deflection can be produced with an externally derived signal. Thus, the oscilloscope system can be used to plot one function against another (e.g., Lissajous figures). However, the system is not intended for precise phase-angle measurements.

To use an external signal for horizontal deflection, connect the signal to the HORIZ INPUT connector. Set the HORIZONTAL DISPLAY switch to EXT X10 or X1. The signal is d.c. coupled to the deflection amplifier. The MAG switch is inoperative when the HORIZONTAL DISPLAY switch is set to either external horizontal position.

Dual-Trace Chopped Blanking

A multichannel plug-in unit provides two separate traces on the CRT and thus permits two functions to be displayed simultaneously. Detailed instructions for operating the multichannel plug-in unit in conjunction with the Type 545B Oscilloscope are contained in the plug-in unit instruction manual.

When the multichannel plug-in unit is operated in the chopped mode to obtain a dual-trace presentation, switching transients will be displayed on the CRT. These switching transients can be reduced by placing the CRT CATHODE SELECTOR switch at the rear of the instrument in the CHOPPED BLANKING position.

Intensity Modulation

The Type 545B CRT display can be intensity modulated by an external signal to display additional information. This is done by disconnecting the grounding bar from the EXTERNAL CRT CATHODE connector at the rear of the instrument and connecting the external signal to this terminal. The CRT CATHODE SELECTOR switch must be in the EXTERNAL CRT CATHODE position.

Very accurate time measurements can be made by intensity modulating the beam with time markers and measuring directly from the time markers on the CRT. A positive signal of approximately 20 volts is required to cut off the beam from normal intensity. The low-frequency cutoff point for Z-axis modulation is 600 Hz.

Functional Description

Using the block diagram (fig. 12-36), the following is a brief description of the functions of the various circuits comprising the Type 545B Oscilloscope.

LOW-VOLTAGE POWER SUPPLY.—The low-voltage power supply produces all operating voltages for the oscilloscope with the exception of parts of the CRT circuit. The low-voltage supply provides regulated -150, +100, +225, +350, and +500 volts. It also provides heater voltages and an unregulated +325-volt output.

VERTICAL PLUG-IN PREAMPLIFIER.—Any Tektronix letter- or 1-series vertical plug-in preamplifier can be used with the Type 545B. For a circuit description of the plug-in unit, refer to the plug-in unit instruction manual.

VERTICAL INPUT AMPLIFIER.—The vertical input amplifier is a balanced hybrid amplifier that amplifies the output of the vertical plug-in preamplifier and applies the amplified vertical signal to the trigger-pickoff circuit and the vertical output amplifier.

DELAY LINE.—The push-pull output of the vertical input amplifier is applied through the balanced delay line to the vertical output amplifier. The delay line is a specially braided 186Ω line which delays the application of the vertical signal to the vertical output amplifier for 200 nsec. This provides time for unblanking the CRT and starting the horizontal sweep before the vertical signal reaches the deflection plates. The delay allows the leading edge of a single fast rising pulse to be displayed. The delay line requires no adjustment because of the precision construction.

VERTICAL OUTPUT AMPLIFIER.—The vertical output amplifier is a push-pull cascode amplifier that takes the output of the delay line and amplifies it to a level sufficient to drive the vertical deflection plates of the CRT.

TRIGGER PICK-OFF CIRCUIT.—The trigger pickoff circuit applies a sample of the input waveform to the trigger circuits of both time bases. The trigger is picked off at the output of the vertical input amplifier.

TIME BASE A GENERATOR.—The Time Base A generator provides accurate ramp voltages for the horizontal deflection system, unblanking for the CRT, and a + gate to a front panel connector. The Time Base A generator may be triggered by signals from either internal or external sources.

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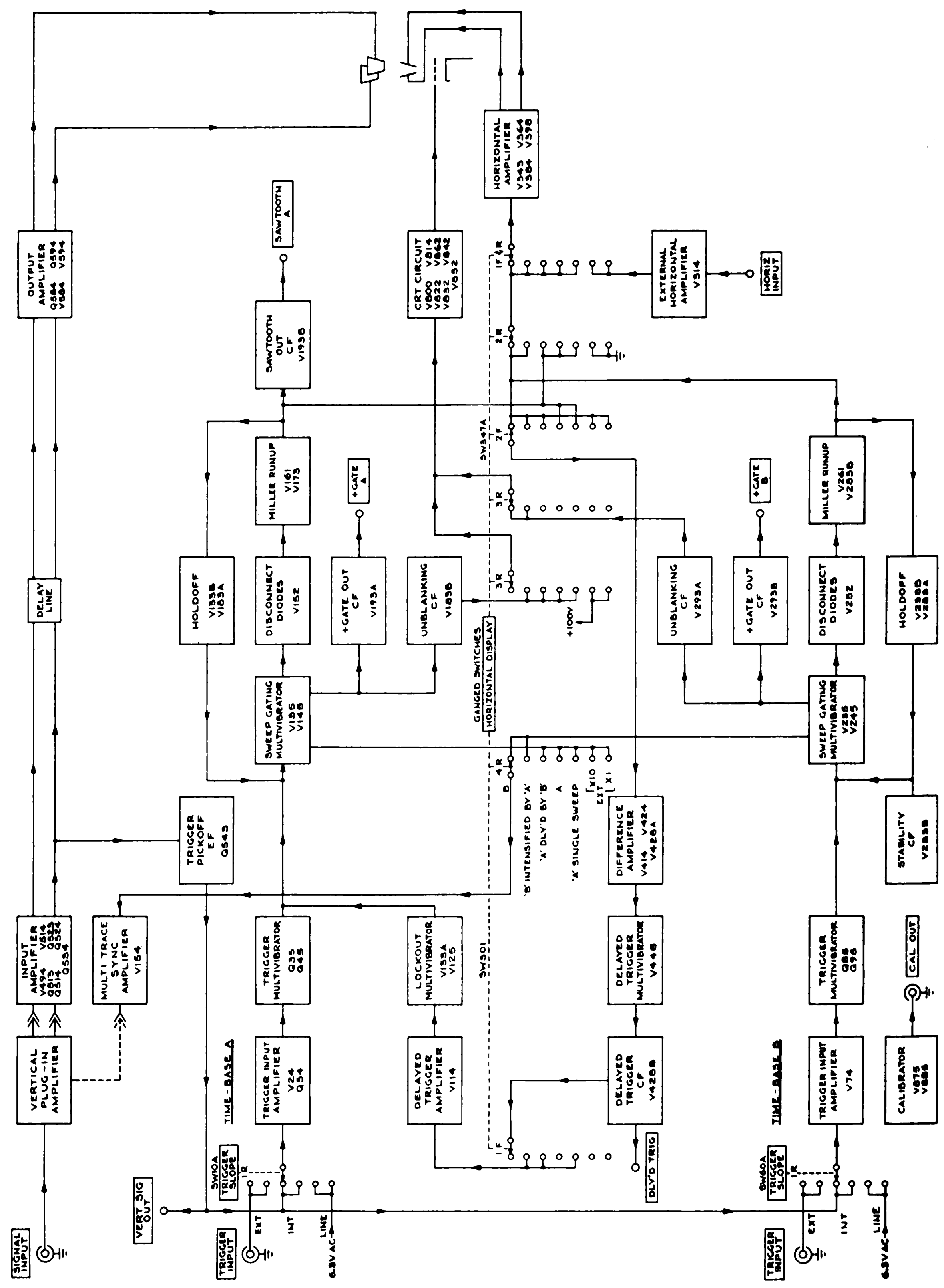
SIGNAL INPUT
VERTICAL PLUG-IN AMPLIFIER
INPUT AMPLIFIER V494 V514 Q513 Q523 Q514 Q524 Q534
MULTI TRACE SYNC AMPLIFIER V154
TRIGGER PICKOFF EF Q543
DELAY LINE
OUTPUT AMPLIFIER Q584 Q594 V584 V594
VERT SIG OUT
TRIGGER INPUT
EXT
INT
LINE
6.3V AC
SW10A TRIGGER SLOPE
1R
TIME-BASE A
TRIGGER INPUT AMPLIFIER V24 Q34
TRIGGER MULTIVIBRATOR Q35 Q45
SWEEP GATING MULTIVIBRATOR V135 V145
HOLDOFF V133B V183A
DISCONNECT DIODES V152
MILLER RUNUP V161 V173
SAWTOOTH OUT CF V193B
SAWTOOTH A
+GATE OUT CF V193A
+GATE A
UNBLANKING CF V183B
LOCKOUT MULTIVIBRATOR V133A V125
DELAYED TRIGGER AMPLIFIER V114
CRT CIRCUIT V800 V814 V822 V862 V832 V842 V852
HORIZONTAL AMPLIFIER V343 V364 V384 V398
EXTERNAL HORIZONTAL AMPLIFIER V314
HORIZ INPUT
SW301
GANGED SWITCHES HORIZONTAL DISPLAY
SW347A
1F
1F R
2R
2F
3R
3R
4R
B
'B' INTENSIFIED BY 'A'
'A' DLY'D BY 'B'
A
'A' SINGLE SWEEP
EXT
X10
X1
+100V
DIFFERENCE AMPLIFIER V414 V424 V428A
DELAYED TRIGGER MULTIVIBRATOR V448
DELAYED TRIGGER CF V428B
DLY'D TRIG
UNBLANKING CF V295A
+GATE OUT CF V293B
+GATE B
DISCONNECT DIODES V252
MILLER RUNUP V261 V283B
HOLDOFF V283B V283A
SWEEP GATING MULTIVIBRATOR V285 V245
STABILITY CF V283B
TRIGGER MULTIVIBRATOR Q85 Q95
TRIGGER INPUT AMPLIFIER V74
TIME-BASE B
SW60A TRIGGER SLOPE
CALIBRATOR V875 V885
CAL OUT

Figure 12-36. — Block diagram of the 545B Oscilloscope.

TIME BASE B GENERATOR.—The Time Base B generator closely resembles the Time Base A generator. Thus, the functions and the circuit description given for the Time Base A generator, in most instances, apply also to the Time Base B generator.

DELAY-PICKOFF CIRCUIT.—The delay-pickoff circuit compares the ramp-voltage output of the Time Base B generator with a variable reference voltage, and assuming identical characteristics in the two halves of the comparator, generates a trigger pulse when the two voltages are equal. The trigger output of the delay-pickoff circuit may be used to arm or trigger Time Base A, and is also available at a front-panel connector.

HORIZONTAL AMPLIFIER.—The input to the horizontal amplifier is selected from the outputs of the Time Base B generator, Time Base A generator, or the external horizontal input amplifier. The selected input is split in phase and amplified to provide push-pull drive to the CRT horizontal deflection plates.

EXTERNAL HORIZONTAL AMPLIFIER.—The external horizontal amplifier provides the necessary gain to drive the horizontal amplifier from external signals. An input attenuator and a gain control provide horizontal deflection factors from about 0.2 to 15 volts/cm.

CRT POWER SUPPLY.—The CRT power supply provides the high voltages for operating the CRT. The power supply is of the RF type, using a 50 kHz Harley oscillator. Secondary windings on the oscillator transformer supply voltages to the high-voltage rectifiers.

CATHODE-RAY TUBE (CRT).—The cathode-ray tube used in the Type 545B is a flat-faced, internal graticule, 5-inch tube with 6 cm of usable vertical scan area. The tube is designed for low-input capacitance to the vertical deflection plates and minimum X-axis center-to-edge defocusing.

CALIBRATOR.—The calibrator in the Type 545B is a multivibrator and cathode follower that provides a square-wave output with a maximum amplitude of 100 volts at a nominal 1 kHz. A step attenuator permits switching the output amplitude from the front panel.

Calibration

The Type 545B Oscilloscope is a stable instrument which will provide many hours of trouble-free operation. However, to insure measurement accuracy, it is suggested that you recalibrate the instrument after each 500 hours of operation or every six months if used intermittently. It will also be necessary to recalibrate certain sections of the instrument when tubes, transistors, or other components are replaced. If any adjustments are made on the power supplies, calibration of the entire instrument should be checked particularly sweep rates and deflection factors.

Complete calibration procedures for this instrument are listed in appropriate sections of the technical manual.

ELECTRONIC COUNTER

The AN/USM-207 is a portable, solid-state electronic counter for precisely measuring and displaying on a 9-digit numerical readout the frequency and period of a cyclic electrical signal, the frequency ratio of two signals, the time interval between two points on the same or different signals, and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz decade steps derived from a 1-MHz frequency standard, frequency dividers, and a frequency multiplier;
2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider;
3. Digital data of the measurement in four-line binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices; and
4. A 1-MHz output from a frequency standard.

The AN/USM-207 (figure 12-37) consists of a major counter assembly, two plug-in assemblies which install in recesses on the front and rear panel, and a group of accessory cables and connectors stored in the detachable front cover.

The major assembly Digital Readout Electronic Counter CP-814/USM-207 contains the input amplifiers; gate control; display; reset and transfer control; frequency multipliers; time base dividers; decade and readout boards; numerical display tubes; decimal point and units indicators; power supply and regulator; and controls associated with these circuits.

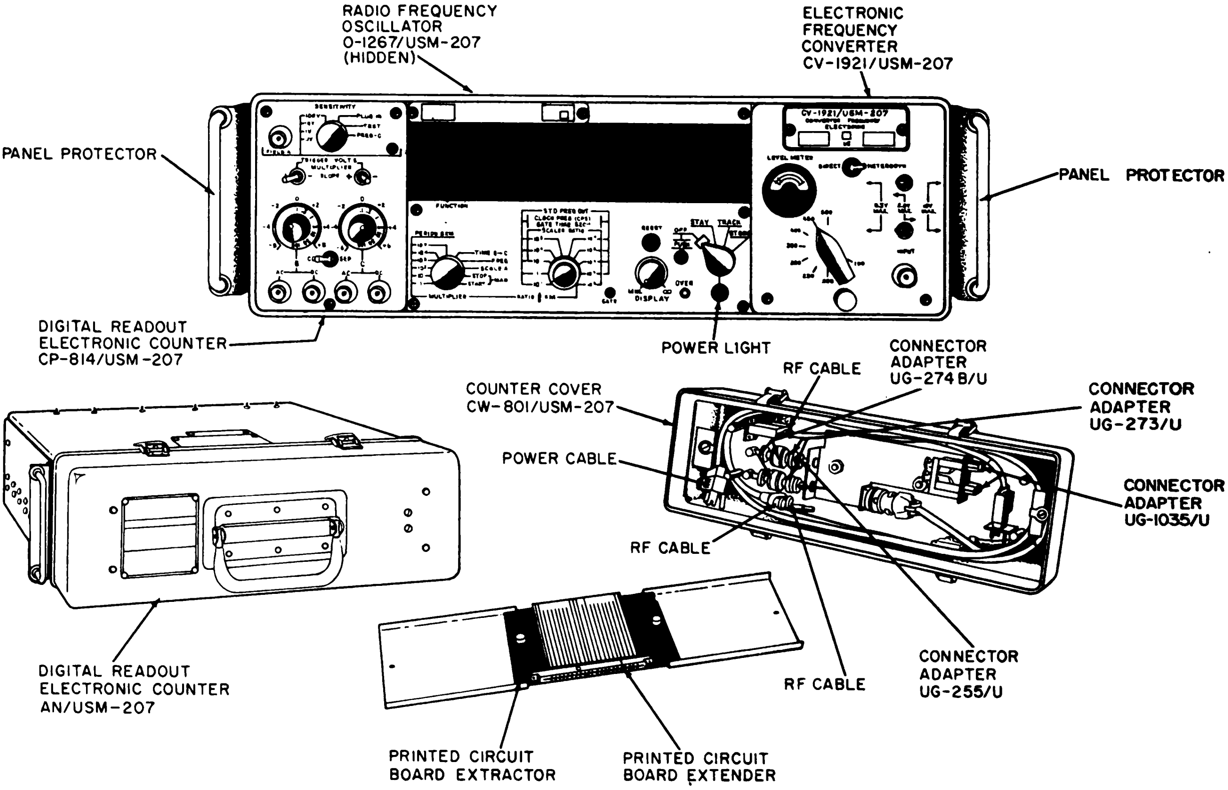
RADIO FREQUENCY OSCILLATOR O-1267/USM-207 (HIDDEN)
ELECTRONIC FREQUENCY CONVERTER CV-1921/USM-207
PANEL PROTECTOR
PANEL PROTECTOR
DIGITAL READOUT ELECTRONIC COUNTER CP-814/USM-207
POWER LIGHT
CONNECTOR ADAPTER UG-274B/U
RF CABLE
COUNTER COVER CW-801/USM-207
CONNECTOR ADAPTER UG-273/U
POWER CABLE
CONNECTOR ADAPTER UG-1035/U
RF CABLE
DIGITAL READOUT ELECTRONIC COUNTER AN/USM-207
RF CABLE
CONNECTOR ADAPTER UG-255/U
PRINTED CIRCUIT BOARD EXTRACTOR
PRINTED CIRCUIT BOARD EXTENDER

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Figure 12-37.—Digital Readout Electronic Counter AN/USM-207.

The Radiofrequency Oscillator O-1267/USM-207 plug-in assembly develops a 1-MHz signal and includes its own power supply. The oscillator includes the 1-MHz output receptacle which may be used as a source of that frequency when the oscillator is connected to a-c power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, scaling the input signal, time interval with external clock, and frequency ratio measurements. For other measurements the counter does not require the oscillator when a separate external 100 kHz or 1 MHz signal is connected. In either of these two situations the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

The Electronic Frequency Converter CV-1921/USM-207 plug-in assembly permits measurement of frequencies up to 500 MHz using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than available with the basic counter. The converter plugs into the right front of the counter.

Figure 12-38 is the overall functional block diagram of the counter. To make a measurement, requires two types of information; a count signal, and a gate control signal. These two signals may be generated within the instrument or they may be supplied from outside sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function the instrument counts the count signal for a period of time determined by the gate control signal. Routing of these signals within the instrument is accomplished by logic circuits. These logic circuits are controlled by means of the front panel controls.

The radiofrequency oscillator (O-1267-USM-207) generates a signal of precise frequency for use throughout the counter or to provide a precise 1 MHz signal for use outside the equipment.

The electronic frequency converter accepts radiofrequencies between 100 MHz and 500 MHz and converts them to radiofrequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The "A" amplifier amplifies the A input signal or the output of the converter for use throughout the counter.

The "B" amplifier amplifies and shapes the B input signal for use throughout the counter.

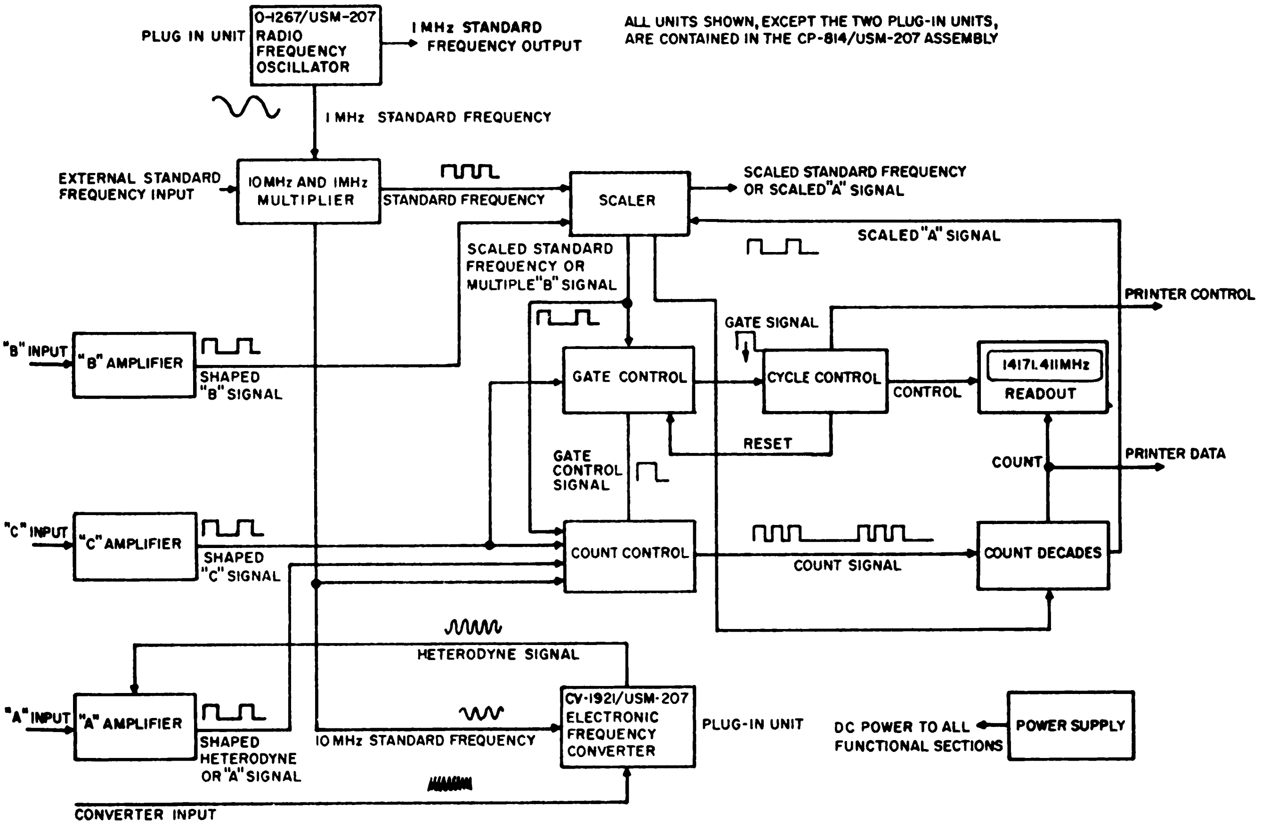
The "C" amplifier amplifies and shapes the C input signal for use throughout the counter.

The 10 MHz and 1 MHz multiplier multiplies the frequency and shapes the signal generated by the radiofrequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and control signals depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades will count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front-panel switches.


PLUG IN UNIT
O-1267/USM-207 RADIO FREQUENCY OSCILLATOR
1 MHz STANDARD FREQUENCY OUTPUT
ALL UNITS SHOWN, EXCEPT THE TWO PLUG-IN UNITS, ARE CONTAINED IN THE CP-814/USM-207 ASSEMBLY
1 MHz STANDARD FREQUENCY
EXTERNAL STANDARD FREQUENCY INPUT
10 MHz AND 1 MHz MULTIPLIER
STANDARD FREQUENCY
SCALER
SCALED STANDARD FREQUENCY OR SCALED "A" SIGNAL
SCALED "A" SIGNAL
SCALED STANDARD FREQUENCY OR MULTIPLE "B" SIGNAL
PRINTER CONTROL
GATE SIGNAL
"B" INPUT
"B" AMPLIFIER
SHAPED "B" SIGNAL
GATE CONTROL
CYCLE CONTROL
CONTROL
14171.411MHz
READOUT
RESET
GATE CONTROL SIGNAL
COUNT
PRINTER DATA
"C" INPUT
"C" AMPLIFIER
SHAPED "C" SIGNAL
COUNT CONTROL
COUNT SIGNAL
COUNT DECADES
HETERODYNE SIGNAL
"A" INPUT
"A" AMPLIFIER
SHAPED HETERODYNE OR "A" SIGNAL
10 MHz STANDARD FREQUENCY
CV-1921/USM-207 ELECTRONIC FREQUENCY CONVERTER
PLUG-IN UNIT
DC POWER TO ALL FUNCTIONAL SECTIONS
POWER SUPPLY
CONVERTER INPUT

162.8

Figure 12-38.—Digital Readout Electronic Counter AN/USM-207 overall functional block diagram.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control. The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the "Store" mode.

The power supply supplies all d-c power required by the basic instrument and the converters and consists of seven d-c supplies. Five of these supplies (+18 volt, +12 volt, +6 volt, and -12 volt) are regulated and two (+180 volt and +45 volt) are unregulated.

SIGNAL GENERATOR

AN/USM-44

The AN/USM-44 Signal Generator is a general purpose test instrument capable of furnishing accurately adjustable radiofrequency signals from 0.1 microvolt to 0.5 volt in amplitude over a frequency range from 10 to 420 MHz. The instrument may be amplitude modulated by internally generated sine waves or by externally applied sine waves or pulses. The AN/USM-44 includes a built-in crystal-controlled heterodyne calibrator which permits the operator to adjust the output frequency to a high degree of accuracy. This particular circuit includes a front panel switch for selecting either of two beat frequencies, 1 or 5 MHz, which will appear throughout the range of the signal generator. The output signal level is adjusted by an attenuator, calibrated in both volts and decibels below 1 milliwatt (dbm), and can be read directly to an accuracy of ±2 db over the full frequency range without the use of external pads, monitoring devices, or charts. The instrument features straightforward operation through the use of reliable, direct-reading controls and meters throughout. With its high quality output signal, the AN/USM-44 is especially suitable for applications requiring a minimum of incidental amplitude or frequency modulation.

Electrical Characteristics

Signal Generator AN/USM-44 is capable of generating a continuously adjustable RF output signal throughout a frequency range of 10 to 420 MHz, as indicated on a direct-reading dial. The frequency dial calibration is accurate to better than 0.5%. Calibration accuracy may be improved by employing the crystal-controlled heterodyne calibrator, which provides checkpoints at every multiple of 5 MHz over the entire frequency range of the equipment. The frequency dial index is adjustable by a small knurled knob on the front panel so that the dial calibration can be set exactly on frequency at any calibrator checkpoint. The checkpoint signals are obtained by connecting a headset (not part of the equipment) to the XTAL CAL. OUTPUT jack. The calibrator is accurate to ± 0.01% of 5 MHz, provides better than 0.1 milliwatt of power to a 600-ohm headset, and is adjustable in output by the XTAL CAL. GAIN control. In addition to the above, Signal Generator AN/USM-44 provides checkpoints of 1 MHz over the entire frequency range of the equipment.

An output attenuator, calibrated to be read directly in both volts and decibels, provides continuous adjustment of the output signal from +4 to -127 dbm (350 millivolts to 0.1 microvolt) and may be read to an accuracy of ±2 db or better over the entire frequency and attenuation range when the instrument is connected to an external 50-ohm resistive load. The internal impedance of the generator, as seen at the output jack, is 50 ohms over the full frequency range; when connected to a 50-ohm resistive load, the VSWR due to mismatch will not be greater than 1.2 (SWR of 1.6 db).

The RF output signal may be amplitude modulated by internally generated 400- and 1000 Hz sine waves or by externally applied sine waves above 4 volts rms over a frequency range from 20 Hz to 100 kHz or by externally applied pulses above approximately 10 volts. When pulse modulated, the instrument is capable of generating pulses of radiofrequency energy as short as 4 microseconds at RF signal frequencies above 40 MHz and as short as 1 microsecond above 220 MHz. The degree of sine wave modulation is continuously variable from 0 to 95% by a front panel control. Modulation of the RF signal is continuously displayed on a direct reading percent modulation meter having an accuracy of ±10% or better.

The AN/USM-44 is especially suitable for aligning narrow-band AM receivers. In such applications, during actual receiver alignment, a significant amount of spurious FM in the generator may result in mistuning of the receiver due to unwanted detection by the selectivity characteristic of the IF amplifier in the receiver. To keep spurious FM to a negligible value, the instrument employs a master oscillator-power amplifier (MOPA) type of RF generator circuit. Modulation is introduced at the power amplifier stage and has little or no effect on the frequency of the oscillator. A buffer stage between the oscillator and amplifier further isolates the oscillator. The effectiveness of these measures is such that spurious FM is less than 0.001% at 30% modulation for frequencies below 100 MHz and less than 1000 Hz above 100 MHz.

Operating Controls

The front panel operating controls, dials and terminals for the AN/USM-44, are listed along with their functions in table 12-2 and are shown in figure 12-39. A simple block diagram showing which circuits in the signal generator are affected by the various front panel controls is shown in figure 12-40.

Continuous Wave Operation

For CW operation the AN/USM-44 supplies a continuous wave output signal of up to 5 milliwatts in power across an external 50-ohm load (0.5 volt) with the output level directly indicated to an accuracy of better than ±2 db for all conditions of operation. The AN/USM-44 has an output level calibration accuracy of ±1 db over the entire frequency and attenuation range. When set for CW operation, the MOD. LEVEL control is inoperative and may be set to any position; however, the PERCENT MODULATION meter monitors the output signal during all types of operation and may display momentary fluctuations resulting from switching transients.

Internal Sine Wave Modulation

For internal sine modulation of the RF output signal, the signal generator supplies the same quality RF signal as for CW operation modulated by either 400- or 1000 Hz internally generated sine waves as selected by the MOD. SELECTOR switch. The modulating frequencies are accurate to within ±5%, and the modulation envelope contains less than 5% distortion for modulation percentages up to 30%, less than 10% at 50% modulation. Percent modulation is continuously adjustable from 0 to 95% by the MOD. LEVEL control at RF power levels of 0 dbm or less. Incidental frequency modulation resulting from amplitude modulation of the output signal is extremely low, being only a few hundred Hz for reasonable modulation percentages. For modulation percentages below 50%, the frequency modulation index will not exceed 1.0. Output frequency and power levels are set in the same manner as for CW operation.

External Sine Wave Modulation

For external modulation, a signal source generating frequencies from 100 to above 20,000 Hz with an amplitude of approximately 4 volts, must be connected through an appropriate cable to the EXT. MOD. jack on the signal generator. The modulation is of the same high quality as that obtained with internal modulation. The degree of modulation is also continuously adjustable by means of the MOD. LEVEL control and is indicated directly on the front panel PERCENT MODULATION indicator. Percent modulation is continuously adjustable from 1 to 95% by the MOD. LEVEL control with the attenuator set to 0 dbm or less. The input impedance at the EXT. MOD. jack is approximately 50,000 ohms.

Pulse Modulation

For pulse modulation, a pulser generating positive pulses from 10 to 50 volts in amplitude must be connected through an appropriate cable to the EXT. PULSE jack on the signal generator. For pulse operation, the signal generator produces essentially no RF output signal until an external positive pulse is applied to the EXT. PULSE jack. The resultant RF output pulse from the signal generator is of good quality at RF frequencies above 100. The output pulse is free of transients and has low residual signal between pulses. Any input pulse above 10 volts will modulate the RF output signal 100%. The peak level of the RF output pulse will be within 1 db of the CW level established by the same settings of the OUTPUT LEVEL control and output attenuator. The amplitude of the modulation pulse is not adjustable by the MOD. LEVEL control.

Signal Generator Loading Considerations

When using the AN/USM-44, the external load connected to the instrument should be 50 ohms resistive for best accuracy of indicated output

Table 12-2.—AN/USM-44 controls and terminals

REF. NO.	DESIGNATION	FUNCTION
1	Power Receptacle	Receives power from power cord supplied.
2	AC 3 AMP (fuse)	Protects power source and instrument against short circuits.
3	SPARES (fuses)	Replacement 3 amp fuses.
4	DC 0.25 AMP (fuse)	Protects the internal power supply against short circuits.
5	SPARES (fuse)	Replacement 0.25 amp fuse.
6	HEATER (pilot lamp)	Pilot lamp indicates power is applied to generator and space heaters are in operation.
7	Power Switch	In the ON position all circuits of the signal generator are energized. In the off position space heaters are energized.
8	POWER (pilot lamp)	Pilot lamp indicates when main circuits are energized.
9	MOD. SELECTOR	Adjusts signal generator circuits for desired type of operation.
10	FREQUENCY RANGE (selector)	Selects frequency range and positions the range pointer on MEGACYCLES (MHz) dial.
11	FREQUENCY	Controls the output frequency in combination with the FREQUENCY RANGE switch.
12	MEGACYCLES (indicator)	Indicates frequency of the r-f output signal directly in megacycles (MHz).
13	AMP. TRIMMER (control)	Tunes r-f power amplifier for maximum output.
14	OUTPUT LEVEL (control)	Adjusts the r-f power level existing at input to output attenuator.
15	OUTPUT VOLTS-DBM (indicator)	Indicates r-f power level existing at input to output attenuator.
16	Output Attenuator (control)	Selects and indicates the r-f output signal level in microvolts, millivolts, and decibels.
17	RF OUTPUT (jack)	Output connector for r-f output signal (see CAUTION).
18	XTAL CAL. OUTPUT (connector)	Connects headset to crystal calibrator.
19	XTAL CAL. GAIN (control)	Adjusts loudness of beat frequency signal from frequency calibrator.
20	EXT. MOD. (jack)	Receives sine wave from external source for modulation of r-f output signal.
21	MOD. LEVEL (control)	Adjusts modulation percentage to desired value.
22	PERCENT MODULATION (indicator)	Indicates the percentage modulation of the r-f output signal.
23	ZERO (screwdriver adjustment)	Electrically sets the modulation meter to zero with instrument in operation with no modulation applied.
24	EXT. PULSE (jack)	Receives pulses from external source for modulation of the r-f output signal.
25	Frequency dial index adjustment	Adjusts frequency dial index over short range.
26	Frequency dial lock	Locks frequency dial.
27	Attenuator dial lock	Locks attenuator dial.
28	FINE FREQ. ADJUST	Adjusts RF OUTPUT frequency in very small increments
29	1 MC OFF 5 MC	Selects 1 megahertz and 5 megahertz outputs or no output (OFF position).
30	Amp. trimmer lock	Locks AMP. TRIMMER control.

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167.795.2

power. The output attenuator indicator has been calibrated by using a "flat" load of 50 ohms.

In most cases, when making measurements on receivers designed to work from a 50-ohm line and antenna the standing wave ratio in the line from the signal generator to the receiver is not significant. The reason for this is that any power reflected from the receiver back toward the generator represents a deficiency in receiver design, and the amount of power lost in such cases is considered as a loss subtractive from the gain of the receiver. A sometimes overlooked factor

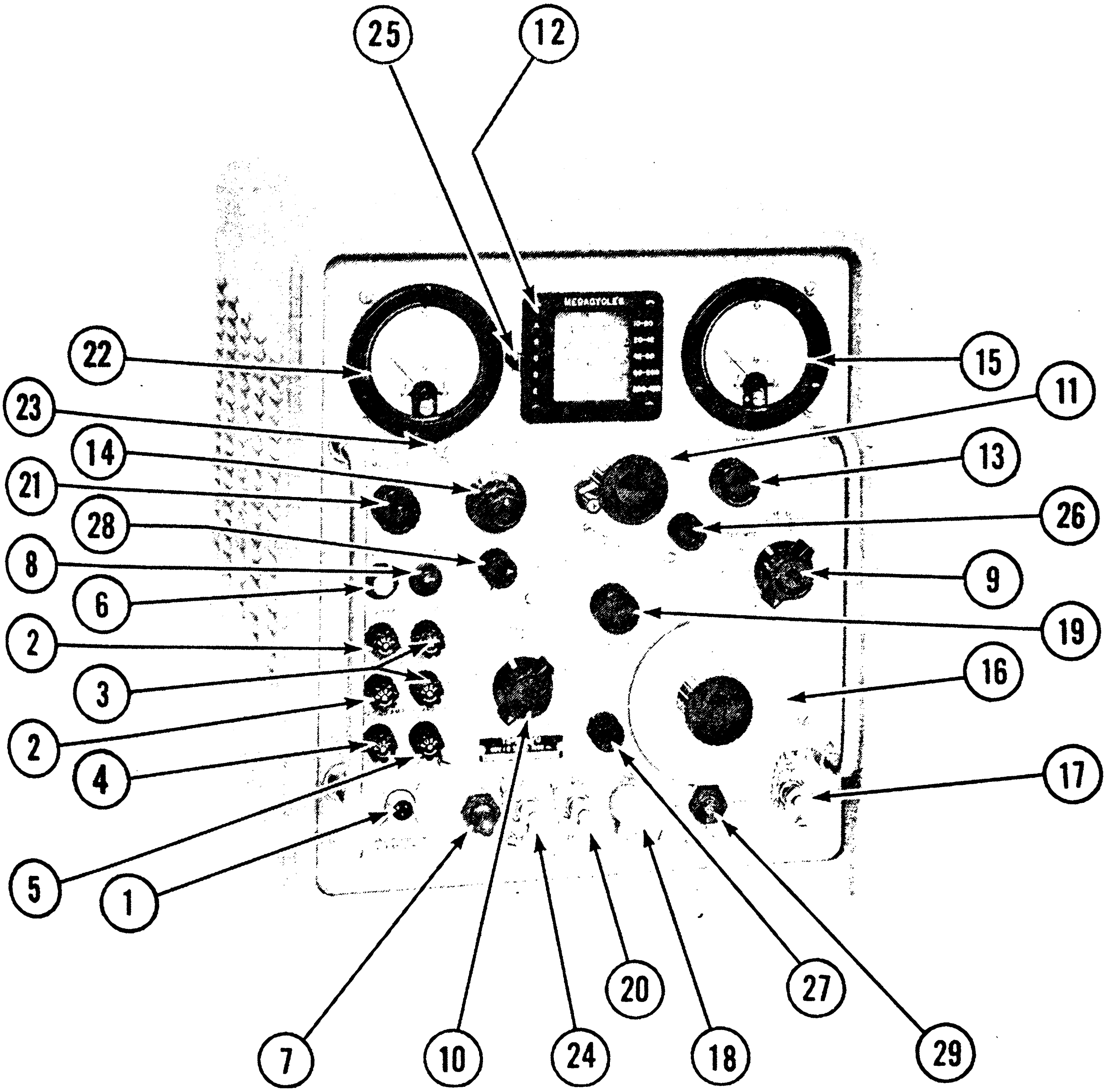

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Figure 12-39.—AN/USM-44 front panel controls.

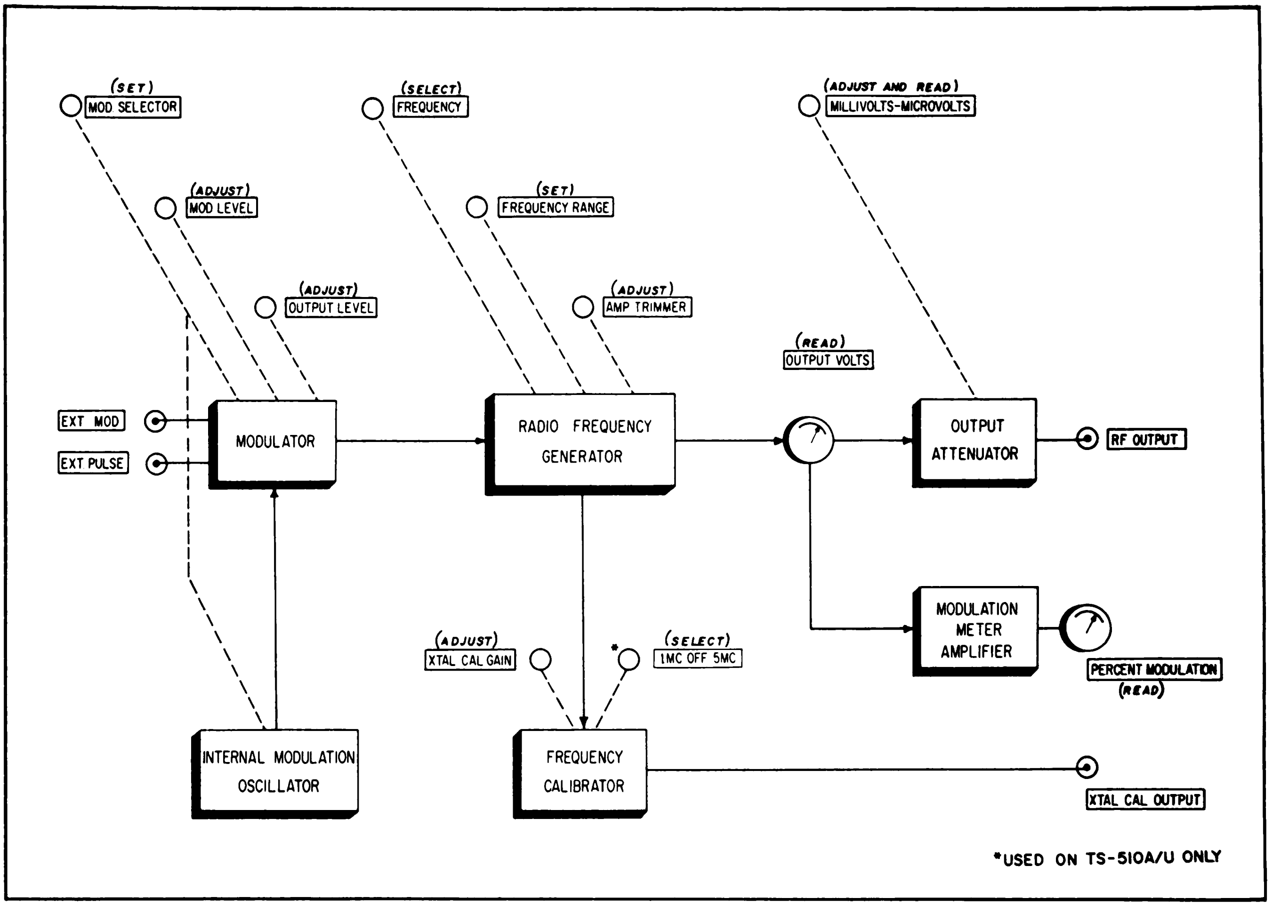

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Figure 12-40.—Diagram of AN/USM-44 showing relationships of front panel controls to major circuits.

which contributes error in high-frequency measurements is the improper assembly of coaxial connectors. A standing wave ratio of several db with attendant error can often be attributed to this cause.

FUNCTION GENERATOR

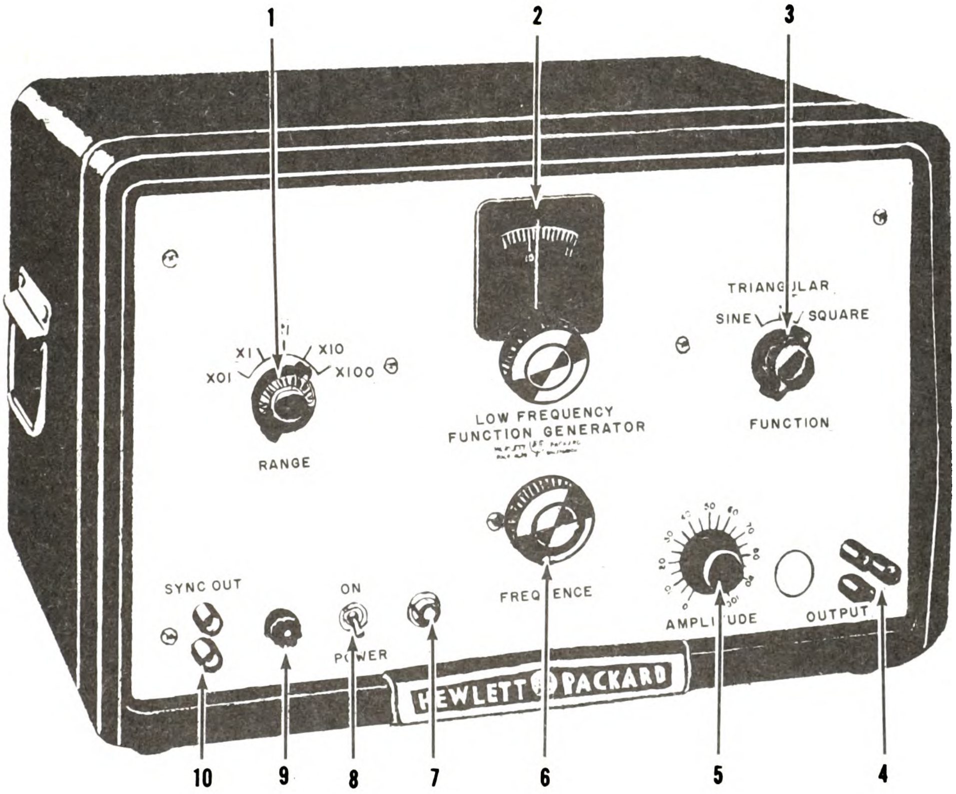
The Hewlett-Packard Low Frequency Function Generator, fig. 12-41, is a source of test voltages between 0.008 and 1200 Hz. The unit can be used for any general purpose low frequency testing application. Three types of output waveforms are available: sine, square, and triangular. A sync output pulse is available for external use.

The low frequency function generator utilizes a relaxation oscillator which is a constant amplitude device. The oscillator produces a square wave from which the triangular wave is derived. The sine-wave function is produced by synthesis from the triangular wave. Output amplitude and distortion are virtually independent of the frequency of operation.

The output of the generator consists of a direct-coupled amplifier designed for either single-ended or balanced output. The unit is rated to deliver at least 30 volts peak to peak to a 4000-ohm load. A negative peak sync pulse of 10 volts is also provided.

System Functioning

Functionally, the unit contains a bistable circuit, linear integrator, sine synthesizer, function selector switch, and output amplifier. The



1. RANGE SELECTOR SWITCH
2. FREQUENCY DIAL AND CONTROL
3. FUNCTION SELECTOR SWITCH
4. OUTPUT TERMINALS
5. AMPLITUDE CONTROL
6. FINE FREQUENCE CONTROL
7. POWER INDICATION LAMP
8. POWER SWITCH
9. FUSEHOLDER
10. SYNC. OUT TERMINALS

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Figure 12-41.—Hewlett-Packard Low Frequency Function Generator, Model 202A.

table circuit produces a square wave; the linear egrator derives a triangular wave from the uare wave; the sine synthesizer derives a e wave from the triangular wave. The function ector switch determines the type of waveform ilable at the OUTPUT terminals, and the put amplifier amplifies the selected waveform.

The block diagram of the low frequency ction generator is shown in figure 12-42. flip-flop arrangement in the bistable circuit duces a square wave at point A. The square ve is fed to the FUNCTION selector switch d the linear integrator. The linear integrator duces a triangular wave at point B which is accurate integral of the applied square wave. The triangular wave is fed to the FUNCTION selector switch, the sine synthesizer, and bistable circuit. A two-way comparator arrangement in the sine synthesizer produces the appropriate triggers for the bistable circuit flip-flop whenever the triangular wave becomes equal to either the plus or minus switching reference (B+ or B-).

The sine synthesizer converts the applied triangular wave into an approximate sine wave and feeds the sine wave (point C) to the FUNCTION selector switch. The FUNCTION selector switch applies either the square, triangular, or sine wave to the output amplifier. The output amplifier amplifies the selected waveform and feeds the amplified waveform to the OUTPUT terminals of the low frequency function generator.

Operating Controls

RANGE selector switch (1, figure 12-41). Selects the desired frequency range to be covered by the frequency dial.

FUNCTION selector switch (3). Selects any one of the three types of output waveforms.

FREQUENCY dial and control (2). Dial (2) is calibrated directly in cycles per second for the X1 frequency range of the oscillator. The knob just below the dial is directly connected to the frequency-varying element. A fine FREQUENCY control (6) provides vernier control for fine frequency adjustment.

AMPLITUDE control (5). Adjusts the amplitude of the oscillator voltage admitted to the amplifier and, therefore, the output of the instrument. This control is calibrated from 0 to 100 in arbitrary units.

OUTPUT terminals (4). Consist of three terminals. The terminal marked G is connected directly to the instrument chassis. The other terminals, vertically aligned, are the OUTPUT terminals. With respect to the ground terminal each of these outputs has equal magnitude of signal, but the two signals are 180° out of phase with each other. The internal impedance between the two OUTPUT terminals is approximately 40 ohms.

SYNC. OUT terminals (10). Provide single-ended pulses for external use.

The following step-by-step procedure should be used as a guide when operating this instrument.

1. Turn the POWER switch, figure 12-41, to ON. The low frequency function generator will operate nearly within specifications after a few minutes warmup. It will be within specifications after 30 minutes.
2. Set the RANGE and FREQUENCY controls for the desired frequency. The frequency dial scale must be multiplied by the multiplying factor indicated by the RANGE selector switch setting to obtain the oscillator frequency. Example: 4 (on dial scale) X 0.1 (multiplying factor indicated by RANGE selector switch setting) = 0.4 Hz.
3. Set the FUNCTION selector switch for the desired output waveform.
4. Connect the equipment under test to the OUTPUT terminals.

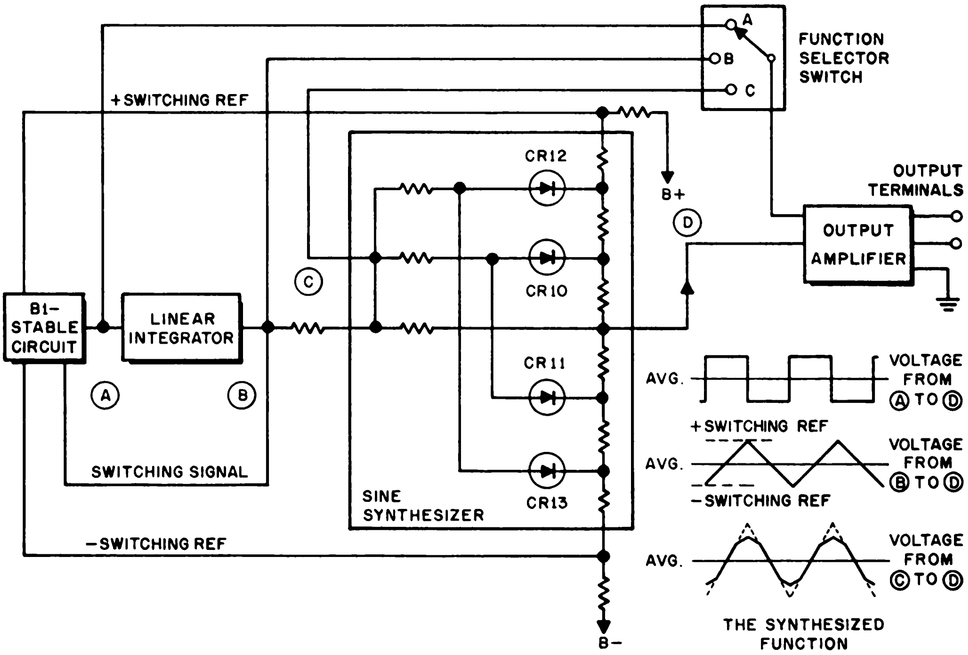

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Figure 12-42.—Low frequency function generator, block diagram.

5. Adjust the AMPLITUDE control for the esired output voltage. Because the frequency esponse is rated ±0.2 db, the output amplitude ıay be measured at any convenient frequency, nd the output level will be correct (within these mits) for any other frequency.

ingle-Ended Output

The terminal marked G is isolated from the ctual OUTPUT terminals. For single-ended peration terminal G must be connected to one f the OUTPUT terminals, and the straped pair ill then be the ground side of the output, gure 12-43A.

alanced Output

Connect the two OUTPUT terminals, figure 2-41, to the equipment being supplied and erminal G to the chassis of the equipment eing driven. Under these conditions, the internal npedance from either OUTPUT terminal to round is 7900 ohms in series with 1μf capaitor, C29. A maximum d-c voltage of 400 volts ay be applied between OUTPUT terminal and the terminal without damaging the 1μf capacitor, 29. The 40 ohms internal impedance (resistive) ill shunt the impedance existing between the two ignal inputs of the system being driven, figure 2-43B.

ync Output Pulse

The SYNC. OUT, figure 12-41, provides a egative pulse of less than 5 microseconds uration and at least 10 volts peak amplitude. occurs on one of the sine and triangular rests and at the rise or fall of the square ave. It occurs at the positive crests with respect to one of the OUTPUT terminals and at the negative crest of the other. Therefore, it can be changed by 180° with respect to the output by reversing the connections to the two OUTPUT terminals which are otherwise completely interchangeable. The SYNC. OUT terminal marked G is directly connected to the chassis.

RADAR TEST CONSIDERATIONS

A missile fire control radar must transmit RF energy in a form that will enable the radar to meet required minimum performance specifications. Testing a radar for the correct transmission characteristics is normally accomplished by the use of multipurpose test equipment referred to as radar test sets. A typical radar test set will provide the means for checking a radar's transmitted frequency, power, and pulse shape.

A great variety of radar test equipment is utilized aboard SMS ships for checking radar transmission characteristics. It would be impractical, at this time, to discuss radar test sets in terms of specific equipment. We can, however, discuss them in terms of some of the functions they perform.

FREQUENCY MEASUREMENT OF EMISSIONS

A frequency meter is an instrument which is used to provide a simple, reliable and accurate means for adjusting the emitted or resonant frequency of transmitters, field strength meters, receivers, and other tuned detectors or emitters to a desired value. The term frequency meter is sometimes applied to test instruments which measure the frequencies of

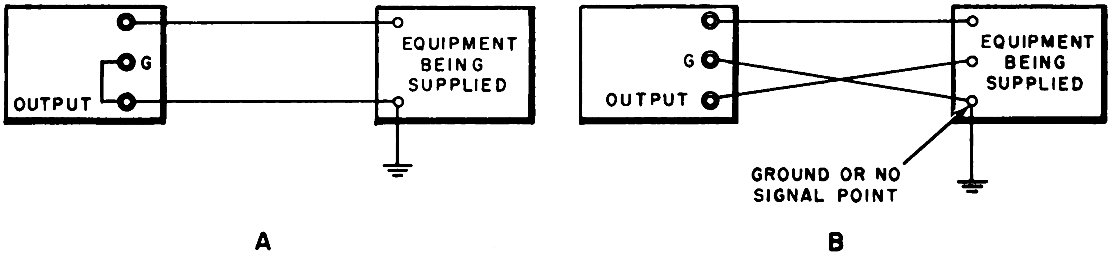

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Figure 12-43.—A. Single-ended output connections. B. Balanced output connections.

external signals and have no provision for emitting a signal. This latter type of instrument is more properly called a wavemeter.

Wavemeters

Wavemeters are calibrated resonant circuits used to measure frequency. Although the accuracy of wavemeters is not as high as that of heterodyne frequency meters, they have the advantage of being comparatively simple and can be easily carried about.

Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low-frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters: the absorption, the reaction, and the transmission types. Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency. The setting of the wavemeter dial is made by observing the grid-current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies.

In figure 12-44 a typical cavity wavemeter is illustrated.

The wavemeter illustrated is of the type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q LC tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, (A) or (D). A crystal rectifier then detects or rectifies, the signal and the rectified current is indicated on the current meter, M.

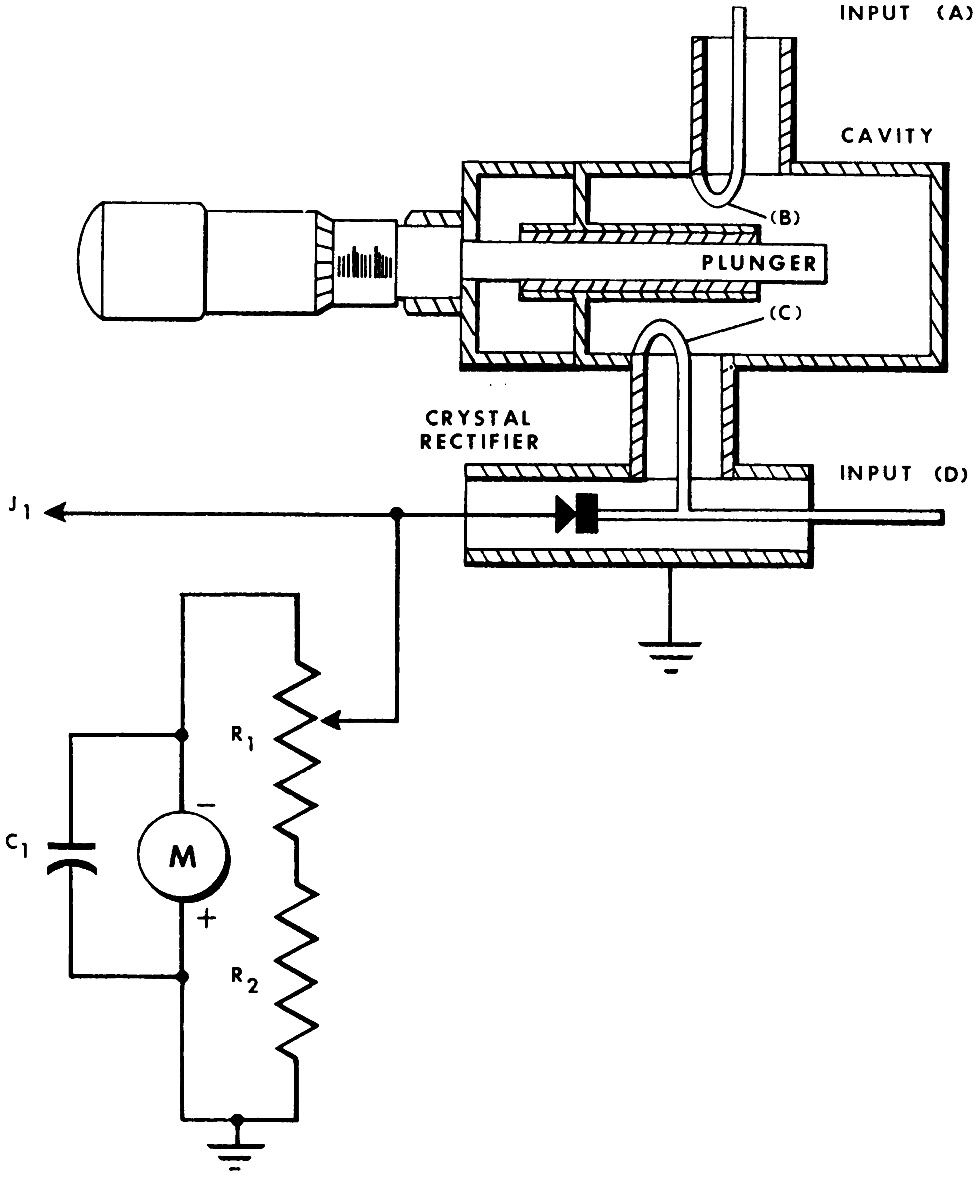
The instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input (A). When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop (B) into the cavity and out through loop (C) to the crystal rectifier where it is rectified and is indicated on the meter. At frequencies off resonance little or no current flows in the detector and the meter reading is small. Therefore, the micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input (D). The RF loop (C) then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the current indicated on the meter dips. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip in the meter, and the resonant frequency is determined from the micrometer setting and the calibration chart.

The potentiometer, R1, is used to adjust the sensitivity of the meter from the front panel of the instrument. J1 is a video jack and is provided or observing video waveforms with a test oscil-oscope.

A directive antenna is used in conjunction with he instrument for making relative field strength easurements of radiated signals, for use in easuring the frequency of radar transmitters, nd for constructing radiation patterns of trans-itting antennas.

In radiation pattern measurements, the directive antenna is connected to the wavemeter input and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading



167.157

Figure 12-44.—Typical cavity wavemeter.

to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper and the field pattern thereby determined.

The frequency of the radar may also be indicated on an oscilloscope. The reduction in power caused by absorption in the resonant cavity is apparent by a decrease in pulse amplitude on the CRT. This dip is usually easier to detect than the power meter dip, as the scope responds more quickly than the power meter. Final tuning, however, should always be done by the meter indication. Transmitter frequency may also be measured during spectrum observation.

POWER MEASURES

In making power measurements on a radar transmitter, there are two methods of sampling the power output of the transmitter. One method uses a pickup horn in front of the radar antenna. When this method is used, the placement of the pickup horn in relation to the antenna is extremely critical as air losses must be taken into consideration. A more satisfactory method is to connect the test set to the radar directional coupler. This avoids the difficulty of measuring or calculating air losses.

The radar test set used in this discussion can be related to the AN/SPM-5 or the AN/SPM-15. These radar test sets are discussed further in the Talos, Tartar and Terrier supplements of this textbook.

When the power (in dbm) is read from the attenuator dial, the losses must be added to this figure. This is easily done by adding the attenuation (in db) of the directional coupler and the loss (in db) of the coaxial cable to the attenuator dial reading. The cable losses are usually indicated on a tag attached to the cable and usual values are about 1 db per foot of coaxial cable. The loss (in db) of the directional coupler is found on a tag or nameplate attached to the directional coupler and is usually 20 db or more.

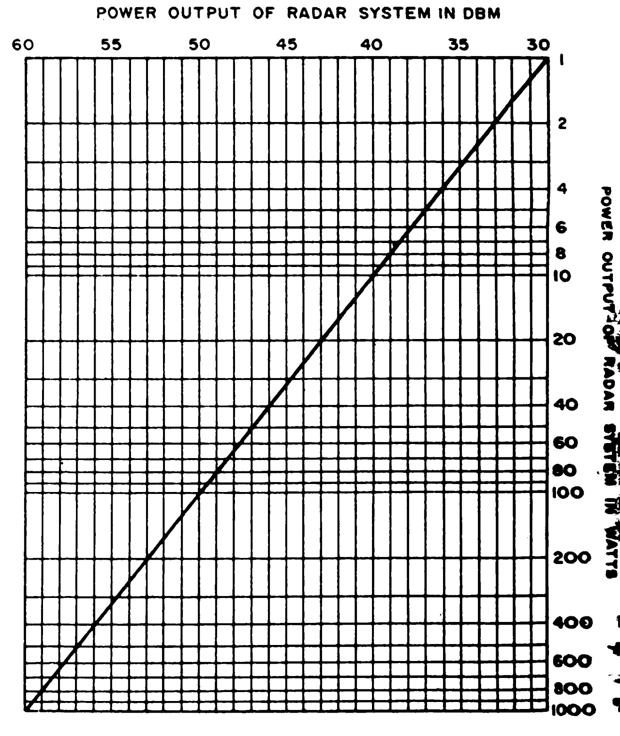
Testing a radar set for average power output might proceed on the following plan: When the test set and radar are warmed up and operating, the appropriate connections are made in accordance with the operation instructions for the test set.

NOTE: Two precautions should be observed when connections are made to the test set. They are as follows:

1. Be sure the attenuation controls are set for maximum attenuation to avoid damaging the test set with power levels that are too high.
2. Turn the frequency meter off resonance so that none of the power will be lost in the resonant cavity.

The attenuation controls are then adjusted to decrease attenuation until the power meter reads 1 milliwatt. The attenuation (in dbm) may then be read from the attenuator dial. To this is added the attenuation of the directional coupler and the coaxial cable. The total attenuation is then indicative of the transmitter power.

Figure 12-45 shows a graph that can be used to convert power in dbm to average power in



AQ.623

Figure 12-45.—Conversion of power in dbm to power in watts.

tts. This can also be accomplished mathe- atically by the equation

$$\text{dbm} = 10 \log \frac{P2}{P1}$$

ere dbm is the total attenuation, P2 is the known output power in milliwatts, and P1 is e 1-milliwatt reference level.

For example, suppose the power measurement r a radar set shows a dial reading of 21 dbm the test set, the directional coupler has 20 db, d the coaxial cable has 1 db per foot and is feet long. Inserting these values in the equation ves

$$49 \text{ dbm} = 10 \log \frac{P2}{P1}$$

earranging and substituting 1 mW (reference wer) for P1 gives

$$4.9 = \log \frac{P2}{1 \text{ mW}}$$

$$10^{4.9} = \frac{P2}{1\text{mW}}; \quad P2 = 10^{4.9} \times 1 \text{ mW}$$

$$P2 = 10^{0.9} \times 10^{4} \times 1 \text{ mW}$$

$$P2 = 7.94 \times 10^{4} \text{ mW} = 79400 \text{ mW}$$

$$P2 = 79.4 \text{ watts.}$$

his corresponds closely to the value of 80 atts that is arrived at when the graph (fig. 2-45) is used.

To find the peak power of the radar, the art shown in figure 12-46 may be used. The RF and pulse width must be known. They may obtained by measurement or from descriptive ta on the radar.

Assuming a pulse width of 0.8 microseconds d a PRF of 1,706 pulses per second, lay a raightedge on the chart, connecting point A ulse length) and point B (PRF). At point C ad the value of db (28.6). This value is added the dbm reading obtained in the average wer measurement and the peak power can en be calculated. To find the peak power in e case previously cited, add 28.6 db to 49 dbm r a total of 77.6 dbm. We cannot use the graph of figure 12-45 in this case as it does not go high enough. However, using the mathematical equation above, the result is

$$77.6 \text{ dbm} = 10 \log \frac{P2}{P1}$$

$$10^{7.76} = \frac{P2}{1 \text{ mW}}$$

$$P2 = 10^{.76} \times 10^{7} \times 1\text{mW}$$

$$P2 = 5.75 \times 10^{7} \times 1\text{mW}$$

$$P2 = 57.5 \text{ kW}$$

Two things become apparent: Peak power is much greater than average power, and a 28.6-db gain represents a tremendous increase in power.

A test equipment employing a bolometer has become the standard instrument for power measurements of RF energy in the higher frequency

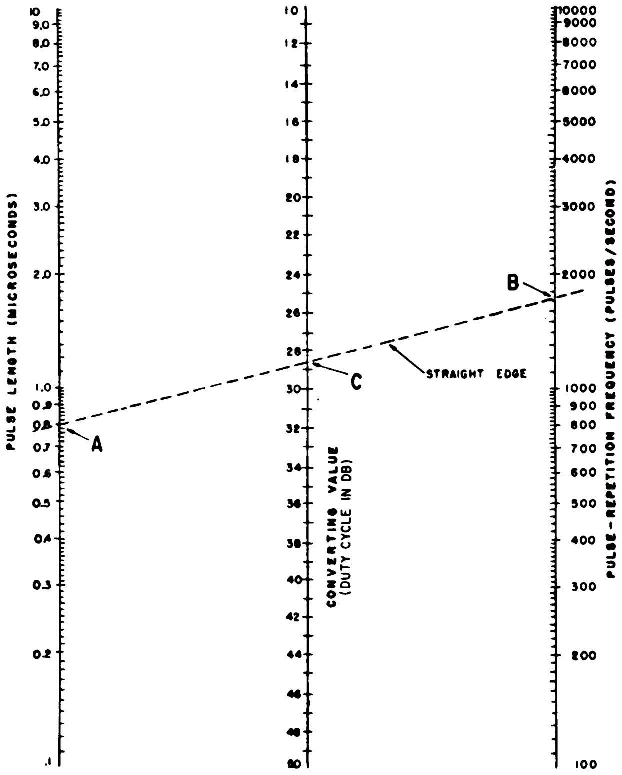


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Figure 12-46.—Average to peak (duty cycle) power conversion chart.

anges. At lower frequencies simpler methods re desirable, even though there is no frequency estriction on the use of bolometers.

Essentially, the bolometer is a loading device hat undergoes changes of resistance as changes n dissipated power occur. There are two chief ypes of bolometers, the barretter and the thermi- tor. The barretter is characterized by an ncrease in resistance as the dissipated power ises, but the thermistor decreases in resistance s the power increases. In the case of either evice, resistance is measured before and after he application of RF power. If the same change n resistance is then produced by a variable -c source of power, the RF power is equal o the measured d-c power. This relationship nakes possible the calibration of a bridge circuit irectly in units of power. In other words, here is one condition of balance when no RF ower is applied, but in the presence of power here is a second condition of balance owing to he resistance change of the bolometer. It is this hange of resistance that is calibrated in power.

arretter

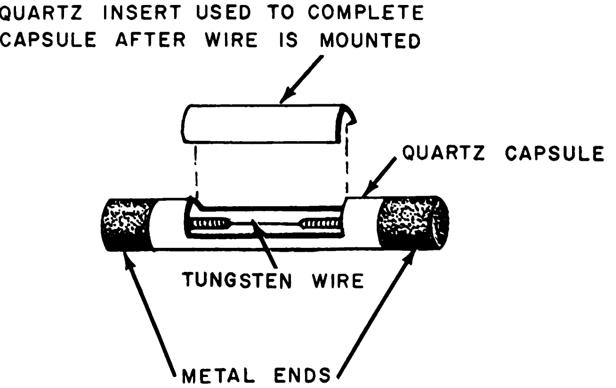
The structure of a typical barretter is shown n figure 12-47. The fine wire (usually tungsten) s extremely small in diameter, so that it is ossible for the RF current to penetrate to the enter and thereby minimize skin effect. It is upported in an insulating capsule between two netallic ends, which also act as connectors. ecause of these physical characteristics the arretter resembles a cartridge type fuse. The nclosure is a quartz capsule made in two parts, the second part of which is an insert cemented in place after the tungsten wire has been mounted. In operation, the barretter is matched to the RF line after the RF power is applied. At lo levels of power, the resistance-versus-pow curve of the barretter is characterized by a square-law relationship.

Thermistor

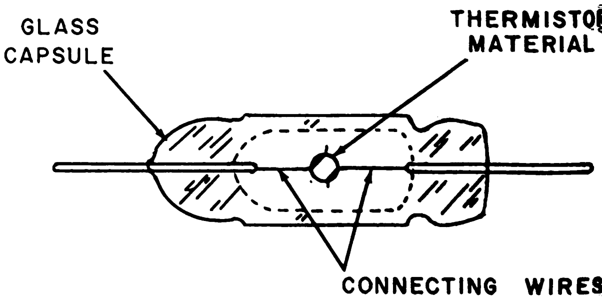
A high degree of precision is made possible by the thermistor, and consequently it is widely used. The negative temperature coefficient comes from the use of a semiconductor as the active material. Figure 12-48 shows a predominant type of construction. Note that the active material is shaped in the form of a head, which is supported between two pigtail leads by connecting wires. The pigtail ends are imbedded in the ends of the surrounding glass capsule.

A thermistor bridge circuit frequently includes other thermistor elements, called compensating thermistors. These thermistors respond to fluctuations of ambient temperature so that the bridge balances, and hence the calibration is maintained over a wide temperature range. Compensating thermistors are usually in disc form so that they can be mounted upon a flat metal surface such as a chassis or wave guide.

The negative-resistance temperature coefficient of thermistors is desirable, because excessive power has the effect of changing the resistance of the thermistor to an extent that causes a pronounced RF mismatch. The resulting decrease in power transfer reduces the likelihood of burnout.


QUARTZ INSERT USED TO COMPLETE CAPSULE AFTER WIRE IS MOUNTED
QUARTZ CAPSULE
TUNGSTEN WIRE
METAL ENDS

167.158
Figure 12-47.—Typical barretter.

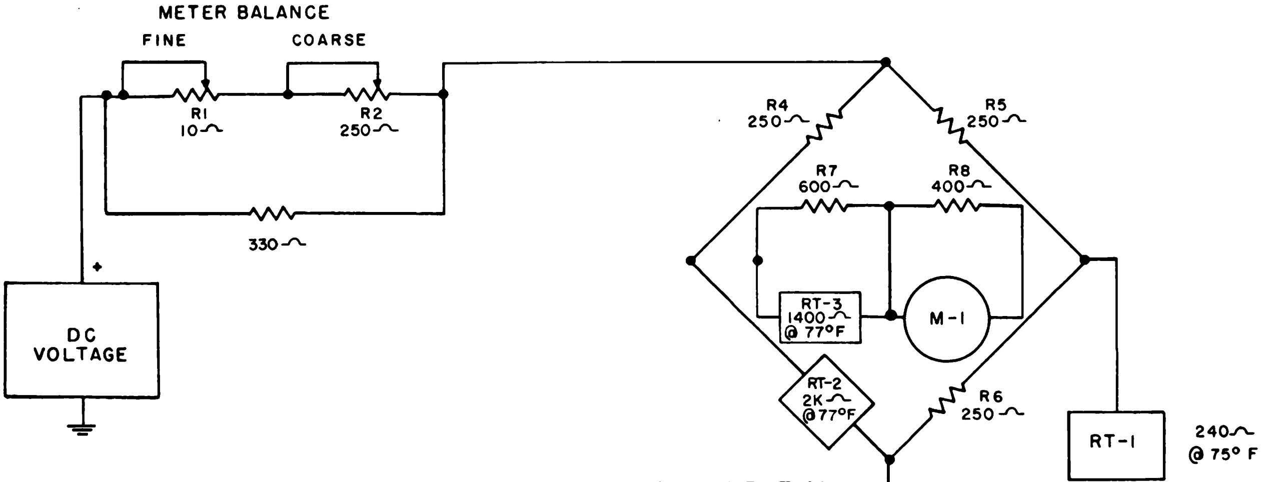


167.159
Figure 12-48.—Bead type thermistor.

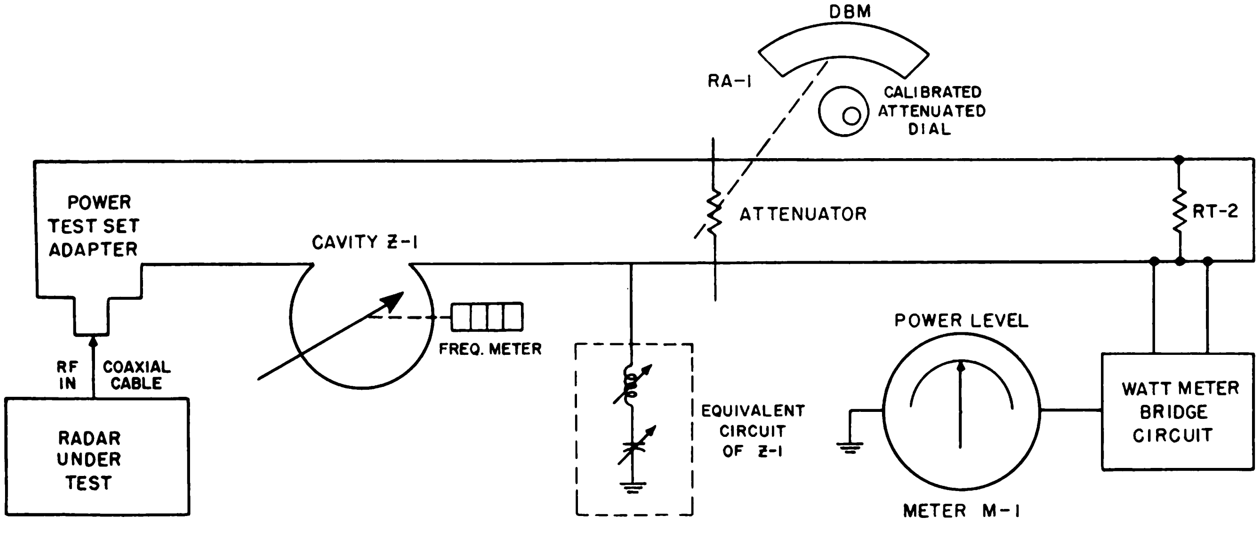
hermistor Bridge

Figure 12-49 is an example of a thermistor ridge utilized for RF power measurements. he thermistor bridge (fig. 12-49B) located in he terminating section of the waveguide contains T2, a bead thermistor, and two compensating hermistors, RT1 and RT3, on the outside of he waveguide. RA1, a calibrated attenuator, ontrols the amount of RF energy applied to RT2.

Prior to applying power, R1 and R2 (fig. 12-49A) are used to adjust the current through RT2. When the resistance of RT2 reaches 250 ohms, the bridge is balanced. Meter M1 reads zero at this time. The RF signal being measured is connected to the test set and applied via the calibrated attenuator, to RT2. This causes the temperature of RT2 to increase, reducing its resistance. The bridge becomes unbalanced, causing meter M1 to deflect an amount proportional to the decrease in resistance of RT2.



A. ELECTRICAL CONFIGURATION



B. PHYSICAL CONFIGURATION

167.160

Figure 12-49.—Average power measurement.

Meter M1, due to the operation of RT2 reads average power.

If the ambient temperature rises, the resistance of RT1 decreases, shunting more current around the bridge network, which allows RT2 to cool. The resistance of RT3 decreases, maintaining meter sensitivity independent of ambient temperature changes.

The cavity (A-1) is an absorption type frequency meter. Frequency measurements are made by adjusting the cavity for a minimum reading on meter (M1).

RECEIVER SENSITIVITY

In chapter 8 you learned the definition of receiver sensitivity as applied to fire control radar. Here we will discuss the two basic methods of measuring receiver sensitivity. One method is the pulse method where a pulse of measured amplitude and width is generated and coupled to the radar receiver. This method is rather difficult as consistent results require that the signal generator be tuned very accurately to the receiver frequency.

The second method employs an FM generator to sweep the signal generator across the receiver frequency. This method insures that the test signal is within the pass band of the receiver.

Pulse Method

With the pulse method, the radar test set (AN/SPM-5 for example) is connected for signal generator operation and set to the receiver frequency. Then the test set signal is adjusted to the 1 mW reference level with the uncalibrated variable attenuator. The DELAY AND SWEEP LENGTH control is used to position and identify the test set pulse on the CRT. The pulse should be positioned away from other targets and ground clutter. (See fig. 12-50(A).)

Radar-receiver gain should be adjusted so the noise signal (grass) on the CRT is about one-half that of the radar-transmitter pulse. The signal gain control on the test set should be adjusted until the grass is about 1/2 inch high. Adjust the PULSE OR GATE WIDTH control to the width of the transmitter pulse. Increasing the attenuation with the dbm control causes the signal to decrease in amplitude. (See fig. 12-50(B).) The attenuation should be increased until the signal is no longer discernible in the grass. (See fig. 12-50(C).) Rocking the delay multiplier control will cause the test set signal to move back and forth, making the test set signal easier to identify in the grass.

The sensitivity of the receiver is equal to the sum of the reading on the DBM control, the attenuation of the directional coupler, and the attenuation of the RF cable. Receiver sensitivity is expressed as a negative dB; that is, -90 db expresses the sensitivity of a receiver than can detect a signal 90 db down from the 1-mW reference level.

FM Method

The FM method of measuring receiver sensitivity offers two main advantages over the pulse method; tuning of the test set to the receiver frequency is not as critical, and receiver bandwidth tests can be made with relatively few changes in test set adjustments after sensitivity tests have been made. The procedure for measuring MDS is given in the steps listed below

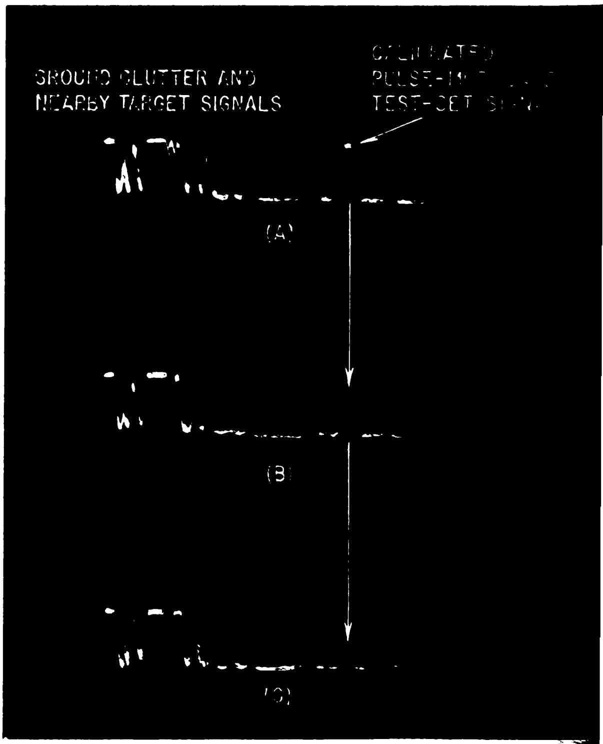


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Figure 12-50.—Measuring receiver sensitiv with pulse generator. (A) Large signal; (small signal; (C) signal just disappearing in noise.

1. Set the SIGNAL-WIDTH control to maximum (CW).

2. Adjust the REFLECTOR control for maximum klystron output as indicated on the power meter.

3. Tune the klystron to approximate radar frequency by adjusting the frequency meter to the frequency of the radar transmitter and tuning the OSC FREQUENCY control for a dip in the power meter reading.

Since the klystron mode is fairly broad, extreme accuracy in tuning the klystron is not necessary. For example, the width of the flat portion of an X-band klystron is about 10 megahertz; therefore, the tuning accuracy required is ±5 megahertz.

4. If necessary, adjust the REFLECTOR control again for maximum output. If a sizable adjustment is required, repeat step 3.

5. Adjust the uncalibrated attenuator for a 1-mw indication.

6. Set the receiver gain control for about /2 inch of grass on the CRT indicator.

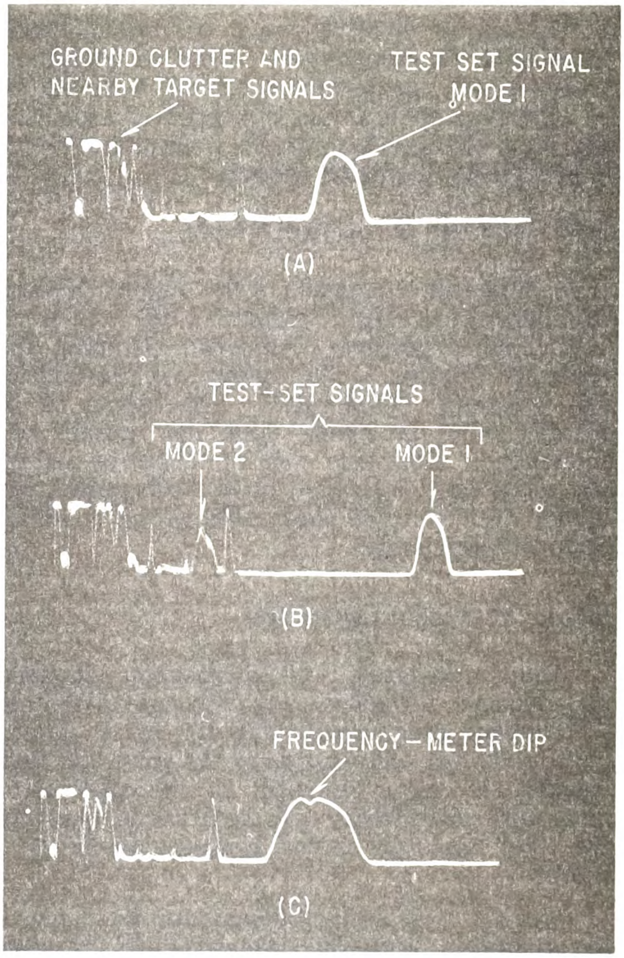
7. Reduce the SIGNAL WIDTH control setting until the pulse is seen on the CRT. (See fig. 12-51(A).) Decrease the attenuation of the dbm control as necessary to obtain a pulse on the CRT.

8. If necessary, adjust the REFLECTOR control to position the echo pulse in a target ree area. If more than one mode of the klystron s visible (fig. 12-51(B)), use the largest one.

9. Adjust the SIGNAL WIDTH control for he desired pulse width. This will normally be he same as the transmitter pulse.

10. Set the DBM control for minimum discernible signal as described for the pulse method f testing receiver sensitivity, rocking the REFLECTOR control to help distinguish the signal.

11. Find the total attenuation in db. The value btained is the MDS in db below 1 mw (-dbm). Total attenuation equals coupling loss plus cable loss plus attenuator reading (all in db).



AQ.627

Figure 12-51.—Measuring receiver sensitivity with an FM generator. (A) Bandpass curve, signal width control near center of range; (B) signal width control near MIN; (C) signal width control near CW, frequency meter dip near center.

SPECTRUM ANALYZER

A spectrum analyzer is a device that sweeps ver a band of frequencies to determine (1) what frequencies are being produced by a specific ircuit under test and (2) the amplitude of each frequency component. To accomplish this, the pectrum analyzer presents, on an oscilloscope isplay, a pattern in which the relative amplitudes f the various frequencies of the spectrum are lotted on the vertical, or Y axis, while the frequencies themselves are plotted on the horizontal, or X axis, of the cathode-ray tube. The overall pattern of this display indicates the proportion of power present at the various frequencies within the spectrum.

The spectrum analyzer can be used to examine the spectra of radar transmissions, local oscillators, test sets, and other equipment operating within its frequency range. Proper interpretation of the displayed spectra enables the technician to determine the degree of efficiency at which the equipment under test is operating. The experienced technician, in many instances, will be able to determine definite areas of malfunctioning component or components within an equipment. In any event, successful spectrum analysis will be dependent upon proper operation of a spectrum analyzer and the technician's ability to correctly interpret the displayed spectra.

COMPONENTS OF A SPECTRUM

A common conception of the output of a pulsed oscillator is a single frequency, which is turned on and off for periods of standard duration. This action is similar to the output of a conventional CW telegraph transmitter. The output of the pulsed radar oscillator does not consist of a fundamental frequency that is turned on and off, but must be considered as a fundamental frequency that is pulse modulated by the waveform of the trigger pulse.

Effects of Modulating Pulses

When modulated, any fundamental frequency will produce a fundamental frequency with sideband frequencies, which collectively is called a spectrum. The distribution of the power on these frequencies is a function of the modulation. Normally, modulation is plotted on an amplitude and time basis as shown in figure 12-52, B, C, and D.

Assume F to be the fundamental frequency of the oscillator. Waveform A shows the fundamental frequency plotted as amplitude against time. The number of periods occurring within one second determines the frequency of the oscillation. The amplitude is represented as proportional to the distance between the negative and positive peaks of one cycle.

In a spectrum pattern, this same frequency and amplitude would be represented as F in figure 12-52E. Points along the horizontal axis represent frequency, which increases from left to right, while distance along the vertical axis above the baseline represents amplitude. Thus, two methods of diagramming the results of amplitude-modulating a carrier frequency are shown.

Assume that F_p1 is a modulation frequency applied to the fundamental frequency, F. This is normally represented on an amplitude-versus-time basis. This same type of modulation is shown by two lines on the spectrum pattern. These lines are marked $F+F_p1$ and $F-F_p1$ in figure 12-52E. The reason for this is that the modulated wave actually represents the results of heterodyning two different frequencies. These frequencies are effectively present in the modulated output, and can be detected by suitable receivers. One of the frequencies is the sum of the two, and the other is the difference. The amplitudes of the new frequencies are each half the amplitude of the modulating frequency.

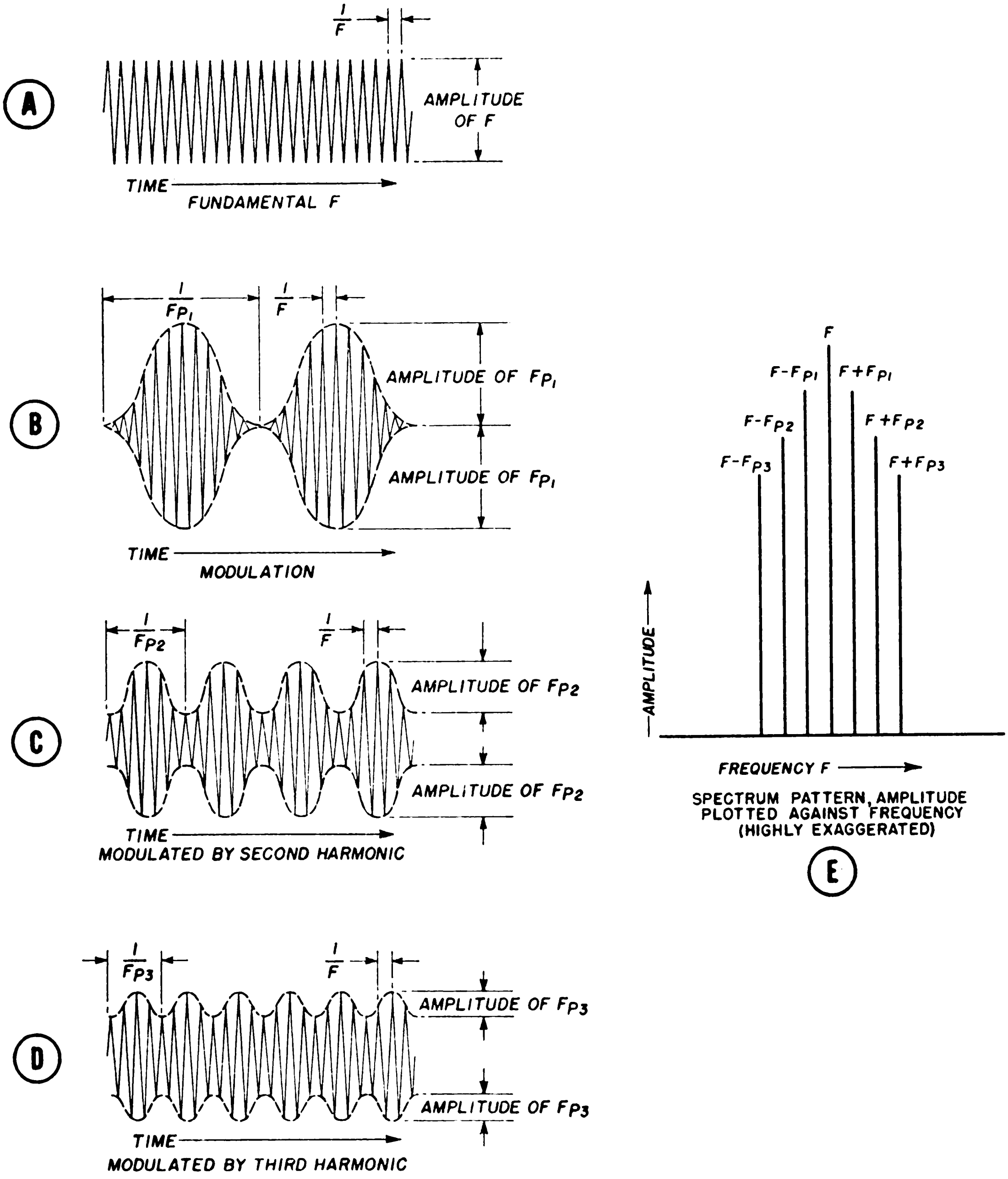
Assume also that a second harmonic of the modulating frequency exists. This is usually of a smaller amplitude than the fundamental of the modulating frequency. Another set of waves will be developed as at C for amplitude-versus-time, and at $F+F_p2$ and $F-F_p2$ on the spectrum pattern.

Additional modulating frequencies will produce additional sideband frequencies. Since these frequencies are normally present in a harmonic relationship, the net result is a number of different frequencies above and below the carrier. The difference between any two adjacent frequencies is equal to the fundamental modulating frequency.

Spectrum of a Pulsed Oscillator

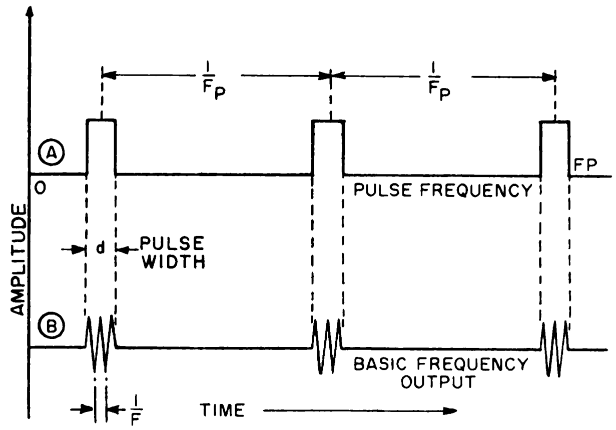
Usually a pulse modulated oscillator is pulsed by the application of a rectangular wave of voltage to an oscillator circuit. A narrow rectangular wave contains an exceedingly wide range of harmonics, including harmonics of a very high order. Consequently, a pulsed oscillator may be assumed to be an oscillator modulated by a modulation frequency that is exceedingly rich in harmonics.

The pulse frequency and the basic frequency of the pulsed oscillator are shown on the amplitude-versus-time graph (fig. 12-53). From this figure, it might appear that the output is simply a pure CW wave of constant amplitude and frequency, turned on for brief intervals of time. This concept cannot be true because of the presence of the modulation frequency F_p1, and the very large number of harmonics, F_p2, Fp3, etc. Therefore, the fundamental modulation frequency and its many harmonics may be considered to modulate the oscillator to produce a fundamental frequency with many sidebands. The net result is a spectrum such as was developed in figure 12-52E, except that it extended to a very large number of frequencies above and below the fundamental frequency. Such a spectrum is shown



92.136

Figure 12-52.—Comparison of amplitude versus time to amplitude versus frequency.



92.137
Figure 12-53.—Output of a pulsed oscillator.

along with the pulse that produced the spectrum in figure 12-54A and B. It is shown that the output of the oscillator consists of an infinite number of lines representing different frequencies. However, because of the harmonic relationship between the modulation frequency and its harmonics, these lines will always be separated by a distance on the baseline that is equal to the fundamental modulation frequency, F_p1.

The amplitude-versus frequency plot provides an envelope, which is of value in estimating the power distribution in the output of a pulsed oscillator. This spectrum as plotted on the spectrum analyzer, is a power spectrum produced by the square law characteristics of the detector. The true power spectrum, which represents the voltage (amplitude) squared, is shown in figure 12-54D.

The power spectrum emphasizes the importance of confining the majority of the power at the fundamental frequency of the pulsed oscillator. The spectrum analyzer can be used in tuning a pulsed oscillator so as to provide the greatest range of power output in the bandpass circuits of a receiver.

Figure 12-54C represents a sample of the spectrum. The figure shows the effective voltage derived from the oscillator frequency spectrum. We can conclude that the pulsed oscillator output contains both frequency and amplitude components. The effect of amplitude modulation is to increase the number of sidebands in the spectrum. The effect of frequency modulation is to increase the amplitude of the side lobes, since the frequency of the oscillation is effectively shifted back and forth between points on each side of its true fundamental frequency.

BLOCK DIAGRAM

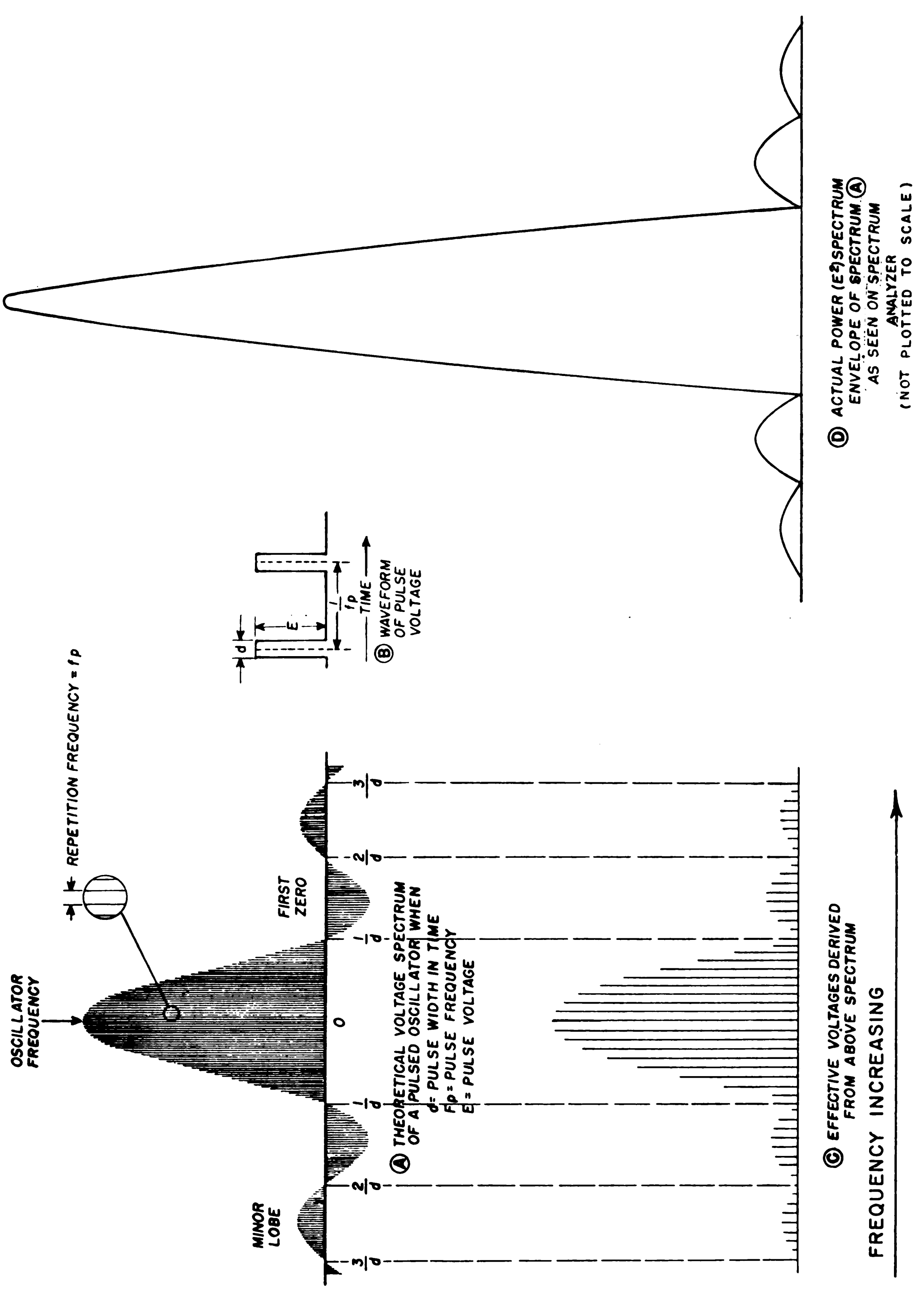
Basically, the spectrum analyzer consists of a superheterodyne receiver with a frequency modulated, RF oscillator (fig. 12-55). The analyzer RF oscillator is modulated with a sawtooth voltage, which causes the oscillator to operate over a range of frequencies. As the frequency of the analyzer RF oscillator increases, it beats with the incoming signal to produce an IF signal for various frequency components present in the spectrum of the received signal. These signals are presented on a cathode-ray oscilloscope as the spectrum pattern.

The RF input is applied to a variable attenuator. The attenuator controls the spectrum amplitude, and consists of two carbonized resistance cards inserted in the RF input end of the waveguide. Varying the contour of these cards varies the degree of attenuation. Maximum attenuation is obtained when the cards are flexed together in the center of the waveguides. The attenuator controls the amplitude of the RF signal either entering the analyzer, or leaving the analyzer when it is used as a signal generator.

The analyzer RF oscillator is a reflex velocity-modulated klystron. It is frequency modulated by a portion of the sweep voltage, which is applied to the oscilloscope deflection plates. The sweep voltage creates a maximum frequency swing in the oscillator output of 40 to 50 MHz. The analyzer RF oscillator output is matched to the load by the fixed attenuator in the waveguide.

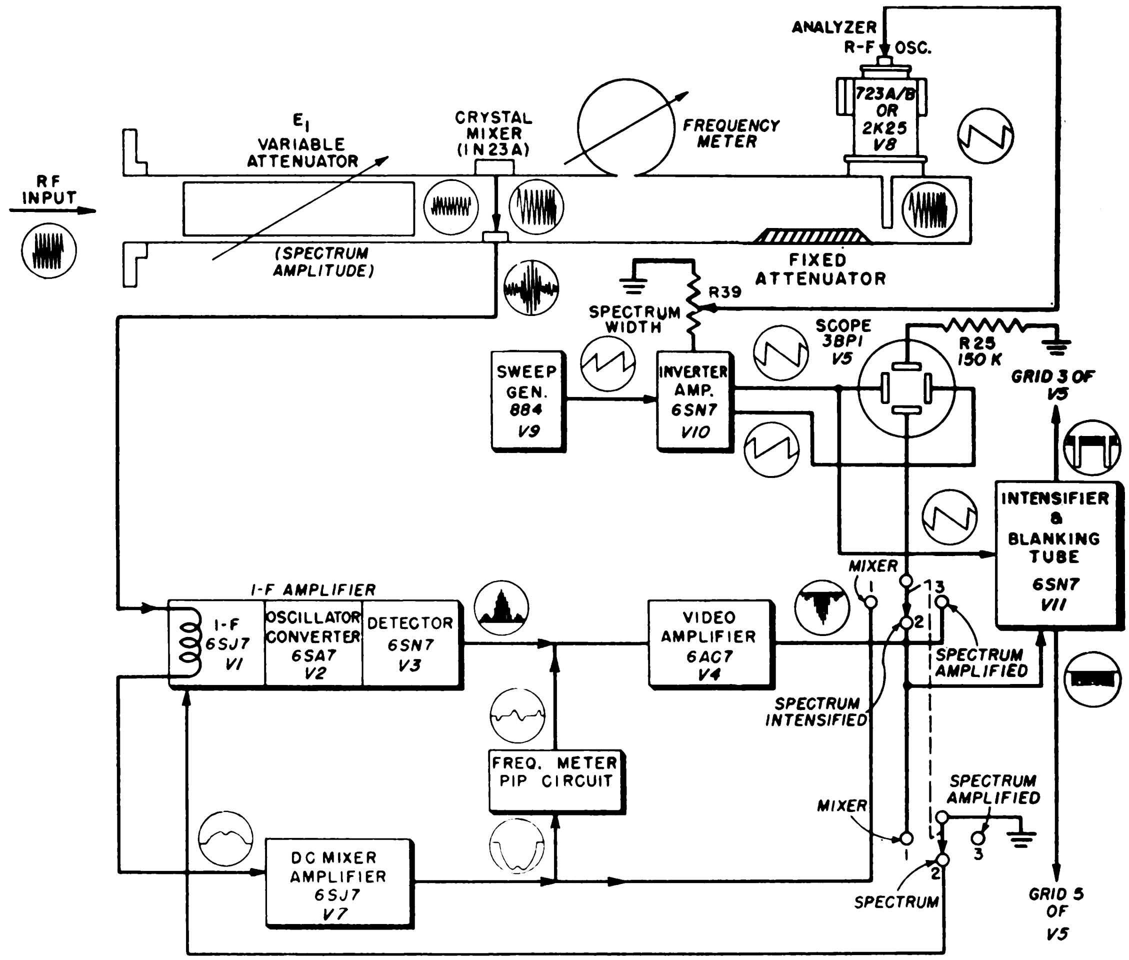
The incoming signal and the output of the RF oscillator are mixed at the crystal mixer. The output is applied to the input circuit of the tuned IF amplifier section to produce the intermediate frequency of 22.5 MHz.

An absorption type frequency meter is mounted in the waveguide at a point between the crystal and the RF oscillator. The meter consists of a cavity with dimensions that can be varied by a front panel control. Each time the frequency of the RF oscillator passes through the resonant frequency of the frequency meter, the meter absorbs some of the RF power. This causes a sharp decrease in the amplitude of the output of the RF oscillator that is applied to the crystal. The change in amplitude is caused to appear on the scope as a sharp pip, which is used as a


OSCILLATOR FREQUENCY
MINOR LOBE
FIRST ZERO
REPETITION FREQUENCY = fp
3/d
2/d
1/d
0
1/d
2/d
3/d
Ⓐ THEORETICAL VOLTAGE SPECTRUM OF A PULSED OSCILLATOR WHEN
d = PULSE WIDTH IN TIME
fp = PULSE FREQUENCY
E = PULSE VOLTAGE
d
E
1/fp
TIME
Ⓑ WAVEFORM OF PULSE VOLTAGE
Ⓒ EFFECTIVE VOLTAGES DERIVED FROM ABOVE SPECTRUM
FREQUENCY INCREASING
Ⓓ ACTUAL POWER (E²) SPECTRUM ENVELOPE OF SPECTRUM Ⓐ AS SEEN ON SPECTRUM ANALYZER
(NOT PLOTTED TO SCALE)

92.138

Figure 12-54. — Relationship between a voltage spectrum and a power spectrum.



92.13

Figure 12-55.—Spectrum analyzer, block diagram.

frequency marker. The pip occurs when the frequency of the RF input coincides with the frequency of the meter.

The output of the crystal mixer is applied to the input circuit of the 22.5 MHz intermediate frequency amplifier. The output of the IF amplifier section is applied to the oscillator-converter.

The oscillator-converter contains a local oscillator operating at a frequency of 19.5 MHz. The intermediate frequency is changed to three megahertz in this stage by beating the 19.5 MHz frequency against the 22.5 MHz from the crystal mixer. The sharply tuned plate circuit of the oscillator-converter produces a 50-MHz circuit bandpass. The output is applied to the detector stage.

The detector section functions as an infinit impedance detector. The rectified output of th detector is applied to the video amplifier.

The video amplifier stage has two inputs. One is the output of the detector, and the othe the frequency meter pip obtained from the d- amplifier through a differentiating circuit. Th output of the video amplifier is coupled to th vertical deflecting plates of the oscilloscope. portion of the video output is used to trigge the intensifying stage.

When the selector switch is in the MIXE position (position 1), the d-c mixer amplifie the output of the crystal mixer and applie it through the selector switch to the vertica plates of the cathode-ray tube for test purposes

In the other two positions of the selector switch, the output of the d-c mixer is applied to the video amplifier. The end pips of the waveshape appearing at the video amplifier grid are derived by differentiation in the plate circuit of the d-c mixer amplifier. The center pip corresponds to the point of resonance of the frequency meter.

The sweep generator is a gas tube relaxation oscillator that generates a sawtooth output at frequencies between 10 and 30 hertz. The output of the sweep oscillator is used to drive the sweep inverter amplifier.

The sweep inverter amplifier provides push-pull deflection voltages for the horizontal plates of the cathode-ray tube. It also supplies modulating voltage to the analyzer RF oscillator and trigger voltage for the blanking section.

When the selector switch is placed in either of the SPECTRUM positions (position 2 or 3), the video amplifier signal triggers the intensifier tube. The output thus produced is coupled to the intensifying grid of the cathode-ray tube.

The input voltage from a section of the sweep inverter amplifier is used to trigger the blanking tube. The output of this tube is applied as blanking voltage to eliminate the return trace that would otherwise appear on the scope screen.

CHAPTER 13

ADMINISTRATION

INTRODUCTION

It may seem strange to include a chapter on administration for FTMs of your present pay grade. But as a member of the weapons department you are a partner in its administration. True, most of your working day is spent on a particular piece of equipment that is but a part of the entire fire control system. Therefore you probably think of yourself as being subjected to administration rather than being a part of it. Essentially, however, it is your work, ability, and training, plus your equipment, that is being administrated; and you have some say in the determination of administrative policies.

The operational and maintenance policies on your equipment are based in part on data obtained from the records and reports that you make. Thus, administration is a tool to aid you, and is well worth the paperwork involved. The assistance you receive from administration is not always apparent and the paperwork is sometimes disregarded or slighted in the name of expediency. When this happens, everyone loses because something is taken away from the organization.

THE IMPORTANCE OF PAPERWORK

Your big job is to keep fire control equipment in top working order. To help you do this, the Navy provides many publications and other written material pertinent to the maintenance task. In return, the Navy requires you to provide written reports on how well you are maintaining your equipment. By a roundabout way there is a constant flow of information between you and the Navy, principally between you and the Naval Ordnance Systems Command (NAVORDSYSCOM).

Your information may leave your ship in the form of a letter or report which is processed by a machine or an individual of the Command. It is probable that information you have supplied will trigger some kind of action in the Command.

To illustrate, let's assume you have sent in five failure reports on the same relay. You may think that this recurring casualty happens only in your particular equipment, but ten other ships have also sent similar reports to the Command. An engineer in the guided missile fire control system section in NAVORDSYSCOM sees a failure pattern and analyzes the relay circuit. He detects a faulty circuit design. Then he makes a change to correct the relay failure. The engineer writes instructions on how to rewire the existing relay circuit and sends these instructions to all ships that have your fire control system equipment. These instructions are called Ordnance Alterations (ORDALTS). If the circuit change is not complicated or requires minor changes to equipment, you will make the circuit alterations. Thus, we have completed a correspondence loop, or in Navy jargon, we have "feedback." This feedback loop system is very important. Any break in the loop destroys the effectiveness of the system. Don't be the one to break it.

Some of the bookkeeping chores you will be involved with are part of your military duties and therefore are covered in Military Requirements for Petty Officer 3&2, NavPers 10058-B. The chapters of particular interest to you at this time are the chapters on "Supply" and "The 3-M System."

PUBLICATIONS

There are many publications used in the proper maintenance of fire control equipment. Technical publications issued by various Systems Commands and Bureaus of the Department of the Navy are sources of important information for every man in the Navy. Publications by Naval Ordnance Systems Command (NAVORDSYSCOM), Naval Ship Systems Command (NAVSHIPSYSCOM), Naval Supply Systems Command (NAVSUPSYSCOM), and the Bureau of Naval Personnel

(BUPERS) concern Missile Fire Control Technicians. The most important publications from these sources that you should be familiar with are discussed in this chapter.

INSTRUCTIONS AND NOTICES

A system is in use throughout the Navy for the issuance of directive type releases, including those which prescribe policy, organization, methods, or procedures, and those which contain information, Certain publications, such as established manuals, operation releases, technical publications, some classified matter, and those joint Army-Navy-Air Force publications which are numbered serially, but do not have separate Army or Air Force designation are excluded from the system.

This program, called the Navy Directives System, provides a uniform plan for issuing and maintaining directives. Conformance to the system is required of all system commands, bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan: Instructions and Notices.

INSTRUCTIONS are directives which contain information or require action of a continuing nature. An Instruction has permanent reference value and is effective until the originator supersedes or cancels it.

NOTICES are directives of a one-time nature and contain information or require action which can be completed immediately. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For reasons of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation, the type of release (whether an Instruction or Notice) a subject classification number; and in the case of Instructions only, a consecutive number. Because of their temporary nature, the consecutive number is not assigned to Notices. This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

NAVORD	INST.	8260.1
(a)	(b)	(c) (d)

(a) Here the authorized abbreviation of the originator of the directive is placed.

(b) This part refers to the type of release, in this case an Instruction.

(c) This is the subject number which is determined by the subject matter of the directive, and is obtained from the Table of Subject Classification Numbers.

(d) Following the period is the consecutive number which is found only on Instructions. An originator would assign consecutive numbers to those consecutive instructions with the same subject classification number. In the example above, the Subject Classification Number 8260 concerns "Guided Missile Fire Control." If the originator, NAVORDSYSCOM, issued additional Instructions dealing with guided missile fire control, they would be assigned numbers, 8260.2, 8260.3, 8260.4, etc. Subject classification numbers are listed in the Table of Subject Classification Numbers found in the current revision of SECNAV Instruction 5215.1. This table contains a numerical and alphabetical listing of numbers with their related subjects, and is of considerable value for reference use when information or instructions of a particular nature are desired. This instruction contains all the necessary information for classifying documents by subject. The major numerical subject group, 8000-8999—Ordnance Material— is of interest to the Fire Control Technician.

A permanent file of instructions that are applicable to the ship is kept in the ship's office. This is the master file of instructions; specific or subject files are kept in the department offices. Thus a copy of all the ordnance instructions should be in the weapons office along with a copy of the current Consolidated Subject Index NavPubInst 5215.4. Suppose we want to see if there are any instructions on the maintenance of a radar antenna. We would look in the index, which lists the instructions alphabetically by subject title. Under radar antennas we find that NAVORD Inst. 8222.1 applies to an antenna maintenance program. We would look at this instruction to see what the program consists of. The instructions are filed numerically.

ORDNANCE PAMPHLETS

The main source of technical information on operation and maintenance of ordnance is the Ordnance Pamphlet (OP). NAVORDSYSCOM publishes these technical manuals, each under its own OP number. They may be prepared by some other naval activity, by the manufacturer, by a commercial specialist in such publications, or by the Command itself. Surface Missile System OPs are of two categories: system OPs and equipment OPs.

System OPs provide the information necessary to operate a shipboard surface-to-air guided missile weapon system in all modes of operation. Information for performing routine maintenance and fault isolation to the level of an independent functional area within a component equipment is also provided.

Equipment OPs provide all the information required by Navy personnel to understand, operate and maintain individual items of equipment. Equipment OPs are applicable to subsystems of weapons systems as well as to separate independent units.

Another category of OPs that you will find of interest are general OPs. General OPs take up a subject matter AREA rather than a specific item of ordnance equipment. Such OPs, of course, do not follow the system and equipment OP structure. But they are written and indexed to serve as a reference book for instruction and training. A good example of this type of OP is NAVORD OP 3000, Weapons Systems Fundamentals. This introduces and explains the fundamental principles of weapons and weapons system components.

The official list of OPs is contained in OP O. It is a consolidated listing of all publications and forms which pertain to ordnance activities. OP O is divided into three parts:

Part 1. NAVORD Ordnance Publications (OPs) consists of a complete numeric listing of all OPs, including Special Projects. Part 1 does not list OPs under preparation, cancelled or obsolete publications.

PART 2. NAVORD Ordnance Data (ODs), explained next. This part consists of a complete numerical listing of all ODs. This part also does not list cancelled and obsolete publications.

Part 3. Subject Index is a listing of all NAVORD OPs and ODs listed in this publication under equipment identification.

Ordnance equipment is changing all the time, and the OPs on every piece of equipment must be kept up to date. This is done by issuing changes. A change is a leaflet or pamphlet that specifies in detail actual text alterations in the OP to which it applies. Changes are issued automatically to the same distribution list as the OP concerned. When received, the changes should be attached inside the front cover of the OP, and the text and illustration changes called for should be entered promptly in the OP itself. There is a good chance you will make these changes. Make every effort to enter the changes as soon as received.

Publications issued between revisions of OP O are listed in the Naval Ordnance Bulletin, a classified publication issued quarterly to give information on new developments and changes.

ORDNANCE DATA

Ordnance Data (OD) are limited-use technical publications covering a wide range of subjects such as installation, overhaul, publication requirements list, the manufacturing process, and manufacture's test data, advance information on ordnance equipment, alignment data, parallax data, and other miscellaneous information, such as tables of weights and dimensions. ODs, like OPs, are listed in OP O.

SMS TECHNICAL BULLETINS

SMS technical bulletins are an important source of information, containing up-to-the-minute data on a particular weapons system. For example, Talos, Terrier, Tartar and Basic Point Defense each has a bulletin source of data. The bulletins serve the need for rapid dissemination of official NAVORDSYSCOM approved material, such as new or revised test procedures, troubleshooting techniques, methods of alignment and adjustment, and other technical information on a system. The information is obtained from fleet commands and units, shore activities, and industrial contractors. Later this information may be incorporated into the OPs and ODs on the system and may result in an alteration to the weapons system. The bulletins are distributed to all installations and activities concerned with the weapons system.

Technical bulletins may call attention to technical problems and to the specific information of related technical manuals which, if followed carefully, should greatly reduce or eliminate the problem; or a technical bulletin may note a problem area for which a solution is being developed which will be covered in an official OP change as soon as the solution has been determined.

NAVORD FORMS

Forms are any printed labels and tags, placecards, signs, decals, drawing formats, form letters, and any other duplicated or printed papers which require clerical fill-ins or have blank spaces for the insertion of information to complete their meaning. Forms are used for requisitioning repair parts, recording information, and reporting. Completing a form requires careful reading and checking the correct answers but it is much simpler and quicker than writing up a narrative report. Besides, it makes possible the accurate tabulation of results which are used as the basis for command decisions at all levels.

Form Numbers

The assignment of a NAVORD form number to a form shows that, before the form is issued, the originating activity has checked the form to make sure it does not duplicate or overlap existing forms. Sometimes the form number is the same as the reporting symbol. But this is not always true. You might even find a form with the same number as the instruction that initiated the form. You can see that there can be confusion in identifying a form or instruction. The program is designed to eliminate and to prevent approval of unnecessary forms; to consolidate all similar forms; to standardize and simplify forms and relate procedures; to ensure economical production, utilization, distribution, and stowage of forms; and to provide a central source of information about all forms.

You can find a list of forms, full information on their distribution, and instructions for requisitioning them in NAVSUP 2002. Incidentally NAVORDSYSCOM welcomes recommendations from the fleet for improvement of the forms. Whenever new weapons or equipment are brought into the Navy, extra reports on all phases are needed so the performance of the new weapons or equipment can be evaluated. New report forms are introduced, tried, and revised, and some are discarded. Detailed instructions are issued to tell you how the reports are to be filled out.

All ships of the operating fleets equipped with surface missile systems shall complete the original and one copy of the Nonexpendable SMS Equipment Status Log, NAVORD Form 8810/2, figure 13-1 for each equipment listed in NAVORDINST 8810.3B. The originals of each week's data shall be forwarded within seven working days after completion to NWS, Seal Beach, Corona, California. The log may be filled in by hand. The yellow copy of 8810/2 will be retained by the ship as its equipment rough log; no other log is required. The information recorded on 8810/2 shall not repeat any maintenance action details that are normally reported on maintenance action form 4790/2K. Use as many 8810/2 forms as necessary to record all information for a seven-day period. Continue entries for the next day on the same sheet if space is available. Make at least one entry at the beginning of every day. This entry should show at least the date, time, and code in appropriate columns (fig. 13-1). A final daily entry should show at least the date, time, status code, and signature of the person completing the form. Procedures for completing 8810/2 are explained in NAVORDINST 8810.2A. The security classification of 8810/2 when filled in will depend upon the content in the Remarks section. If there are no classified remarks, then the form is unclassified and does not need to be marked. Examples of entries which may or may not classify 8810/2 are:

a. Statement that a missile was fired is unclassified.

b. Statement of a missile firing with results of firing is Confidential.

c. Specific missile frequencies are Secret.

d. Routine operations of the equipment, such as DSOTs, tracking operations, loading operations, or system testing are unclassified.

For the appropriate downgrading statement when 8810/2 is classified, see Navy Security Manual 5510.1C.

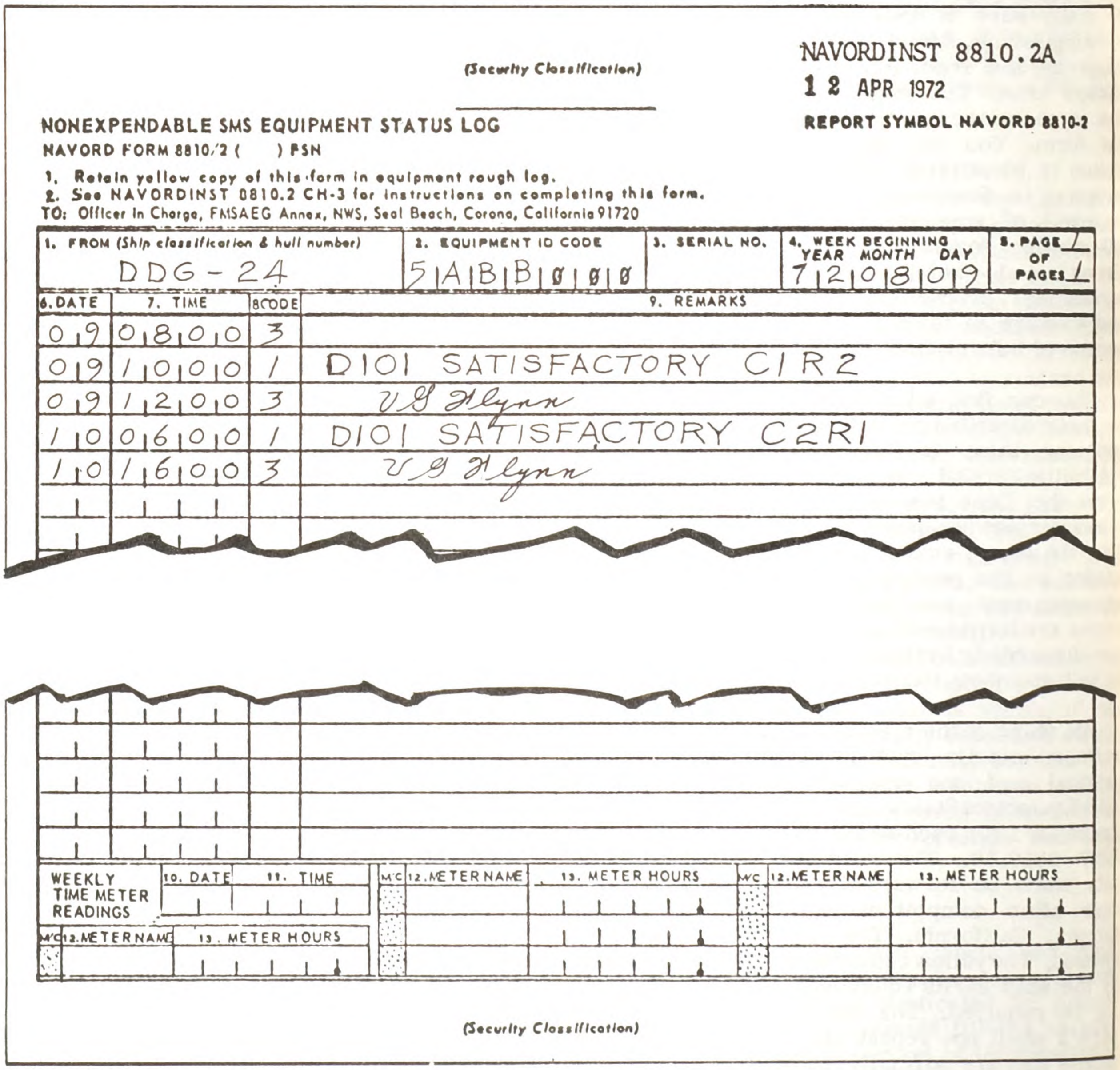
Other instructions that you should be knowledgeable of are NAVORDINST 8810.7, Data Requirements for Surfaced-Launched Missile Firing Tests; NAVORDINST 8810.5, Commanding Officers Narrative Report on Surface Missile Systems; and NAVORDINST 8800.1, Guided Missile Service Record. To be of value in spotting deficiencies in the missile system, the facts recorded in the reports must be accurate. When you supply data to the person filling out the report, be sure you give correct information.

Reports used in the Maintenance Data Collection Subsystem (MDCS) are described in Military Requirements for Petty Officer 3&2, NAVPERS 10056-C, Chapter 13. All the forms described are of importance to you. As a FTM 2 you will be required to assist in the preparation of OPNAV Form 4700-6, Weekly schedule.

The use of OPNAV Form 4790/2K is also described in Military Requirements for Petty Officer 3&2, NAVPERS 10056-C. This is the form you have to fill out when you are unable to complete the maintenance work on a particular piece of equipment and it must be deferred until you can get parts and assistance from a repair facility. OPNAV Form 4790/2K is also used to report certain completed maintenance actions and as a work request. All details on this form must be carefully and accurately filled in. When used for deferred action, it may be several months before you can get repair assistance, and some important information could easily be forgotten in that time, so timely and accurate filling in of the form is essential.

ORDNANCE ALTERATIONS

Alterations to ordnance equipment approved by NAVORDSYSCOM are called OrdAlts. An OrdAlt instruction furnishes the necessary information to accomplish the OrdAlt, while an OrdAlt kit provides the material (hardware) needed for the alteration. A metal OrdAlt plate is attached



(Security Classification)

NAVORDINST 8810.2A
12 APR 1972
REPORT SYMBOL NAVORD 8810-2

NONEXPENDABLE SMS EQUIPMENT STATUS LOG
NAVORD FORM 8810/2 (   ) FSN

1. Retain yellow copy of this form in equipment rough log.
2. See NAVORDINST 8810.2 CH-3 for instructions on completing this form.

TO: Officer In Charge, FMSAEG Annex, NWS, Seal Beach, Corona, California 91720

1. FROM (Ship classification & hull number)	2. EQUIPMENT ID CODE	3. SERIAL NO.	4. WEEK BEGINNING YEAR MONTH DAY	5. PAGE 1 OF PAGES 1
DDG-24	5ABB000		72 08 09	

6. DATE	7. TIME	8 CODE	9. REMARKS
09	0800	3	
09	1000	1	D101 SATISFACTORY C1R2
09	1200	3	V G Flynn
10	0600	1	D101 SATISFACTORY C2R1
10	1600	3	V G Flynn

WEEKLY TIME METER READINGS

10. DATE	11. TIME	M/C	12. METER NAME	13. METER HOURS	M/C	12. METER NAME	13. METER HOURS

M/C	12. METER NAME	13. METER HOURS

(Security Classification)

94.166

Figure 13-1.—Nonexpendable SMS Equipment Status Log Report, NAVORD Form 8810/2.

to each major piece of ordnance equipment. The OrdAlt plate is normally next to the unit's name plate. The number of a completed OrdAlt is stamped on the OrdAlt plate as a permanent record. The accomplishment of an OrdAlt is recorded in the Non-Expendable SMS Equipment Status Log and reported via the Maintenance Data Collection System (MDCS) of the 3-M system. OrdAlt accomplishments are also reported via the Ship Armament Inventory List (SAIL) change report which we will discuss shortly.

OrdAlts are numbered consecutively without regard to the applicability of equipment or vessel. NAVORD OrdAlt 00 is an index of all the OrdAlts that have been issued and that are under preparation. The issued OrdAlts are listed numerically and by the applicable equipment.

Alterations which affect the military characteristics of a ship may be approved only by the Chief of Naval Operations (CNO) and are called NavAlts. If a NavAlt affects ordnance equipment, it is called a NavAlt OrdAlt. Alterations to NAVSHIPSYSCOM equipment are called ShipAlts.

Ship Armament Inventory List (SAIL)

The Ship Armament Inventory List (SAIL) is a list which indicates a ship's Ordnance Inventory and OrdAlt status. This document is the primary vehicle used to define hardware configuration and is used to assemble PMS packages for ordnance equipment. If the SAIL is not kept current the probability that the ship will receive an accurate package is low. Each ship has two copies of the SAIL. Prior to a scheduled overhaul, one copy should be annotated with OrdAlts that have been completed since the ast printing; this copy is sent to NANORDSYSCOM seven months prior to the schedule availability. The other copy is kept on board. Revised copies of the SAIL will be sent to each ship before overhaul. After completion of overhaul, annotate he SAIL to indicate all changes, deletions, dditions, and corrections and forward a copy o NAVORDSYSCOM. Changes made at other times re reported on Ship Armament Inventory List SAIL) Change Report, NAVORD Form 8000/2. NAVORDSYSCOM again revises the SAIL to nclude the changes made at overhaul. When you eceive the revised SAIL, destroy the previous ne.

OAR Program

The OrdAlt Accomplishment Requirement (OAR) is a list issued by NAVORDSYSCOM, as NAVORD Form 8000/3, about six months prior to overhaul of a ship. It shows the OrdAlts in the order of priority of accomplishment, the estimated manhours required for accomplishment, and the estimated cost of each. Within two weeks of receipt of the OAR list, shipboard personnel will notify NAVORDSYSCOM and the overhaul activity of the following:

1. OrdAlt material on board.
2. OrdAlt material on order but not on board.
3. When applicable, special conditions that may exist to warrant installation of conditional OrdAlts.
4. OrdAlts planned for ship's force accomplishment prior to completion of the overhaul period. Shipboard personnel should refrain from requisitioning material for any OrdAlt included on the OAR list unless ship's force accomplishment is planned. NAVORDSYSCOM and the overhaul activity should be notified of any changes that occur which affect the original report.

Upon receipt of the OAR list and the ship's report of OrdAlt material on board, the overhaul activity will order those OrdAlts to be accomplished during the overhaul period.

OrdAlt Assistance

OrdAlt kits for SMS equipment are procured and distributed under the control of the Naval Ship Weapon Systems Engineering Station (NSWSES). When feasible, SMS ships are brought to a particular OrdAlt configuration during a Repair Availability (RAV) or shipyard overhaul; period. This is sometimes referred to as "Block OrdAlting". During these periods, Naval Ordnance System Support Office (NOSSO) may send OrdAlt verification teams aboard your ship to assist you in determining your ship's OrdAlt status/ OrdAlt requirements. These teams are made up of men who are "OrdAlt experts" and they come aboard ship to assist you.

CHANGES TO THE PUBLICATIONS

NAVORDSYSCOM is continuously reviewing its publications to keep them up to date. A vast amount of data on the operation, performance testing, and maintenance of ordnance equipment is received and processed by NAVORDSYSCOM.

When new methods are developed after a publication has been issued, a change to the publication is issued.

No longer are pen and ink changes made to Ordnance Publications. An entire page or section of the publication is changed with change pages provided, along with a change guide.

Changes to a publication are numbered consecutively and should be made in that order. When the changes to a publication become too extensive, a revised edition is issued. The indexes of ordnance publications list the latest revision and the number of changes to each publication.

Types of Changes

Message Changes (MC) are issued when urgently required with respect to hazard type problems. They are concerned with such subjects as personnel, equipment, and ammunition. Message Changes provide NAVORDSYSCOM with the means of rapidly disseminating urgent change information. If you come in contact with this type of change, recognize the fact that they point to hazardous conditions, and expidite their promulgation.

Formal Changes (CH) are formal replacement pages to technical manuals issued to cover configuration changes (OrdAlts and ShipAlts). They will incorporate improvements or an accumulation of corrections including all outstanding MCs, SMS technical bulletins, and action resulting from deficiency feedback procedures.

A change guide provides detailed step-by-step instructions for accomplishing a change. If you become involved in updating ordnance publications, accomplish changes as rapidly as possible and carefully follow the instructions of the change guide.

OTHER PUBLICATIONS

There are some NAVSHIPSYSCOM publications (called NAVSHIPS publications) which are of interest to the FTM. Two such publications are NAVSHIPSYSCOM Technical Munuals and the Electronics Installation and Maintenance Books.

NAVSHIPSYSCOM Technical Manual

The NAVSHIPSYSCOM Technical Manual contains data and instructions pertaining to classes of installed machinery and equipment. The data is in accordance with what is considered the best engineering practice for the operation, maintenance testing, and safety of the equipment. Since the information deals with classes of equipment, it is general information and can provide you with background information that is supplementary to the data contained in the equipment's OP or OD.

The chapters in the "Tech Manual" on electrical and electronic equipment and installations will be of particular interest to you.

Electronics Installation and Maintenance Books

The Electronics Installation and Maintenance Books are published by NAVSHIPSYSCOM to provide subordinate policies, and installation and maintenance information standards for naval electronic equipment. The books are intended to reduce time consuming research on electronic equipment and circuit theory, and contains a great deal of information of interest to the FTM. The books are divided into several volumes; each volume can be ordered as an individual item.

CLASSIFIED PUBLICATIONS

Many fire control publications are classified. Much of this material is in the confidential category. Generally, the responsibility for handling classified matter involes the receipt, accounting for, making changes to, and distribution of all such matter.

Safeguarding Classified Matter

The security of the United States in general, and of naval operations in particular, depends in part upon the success attained in the safeguarding of classified information. Security is not a separate burden to be imposed on personnel, but an integral part of the routine duties performed by personnel. The ideal to be sought by all personnel is that they automatically exercise proper discretion in the discharge of their duties and do not think of security of information as something separate and apart from other things. In this way, security of classified information becomes a natural element and poses no additional burden.

You will find some basic information on security in chapter 7 of Military Requirements for Petty Officer 3&2, NAVPERS 10056-C.

The basic instructions on all classified matters are found in DOD 5200.1, "Information Security

Program Regulation(DODISPR)." The Department of the Navy issued a "Department of the Navy Supplement to the DOD Information Security Program Regulation," OPNAVINST 5510.1. This instruction supplements (DODISPR), DOD 5200.1, by providing necessary instructions and policy guidance applicable to the Department of the Navy. In addition OPNAVNOTE 5510 "Security Information" has been issued to inform commands of current developments relating to security policy. You should become familiar with these publications and use them as the authoritative source of reference wherever a question of security arises.

SHIP'S PLAN INDEX

The plans and diagrams of the fire control equipment are the road maps of maintenance. Generally speaking, there are two basic sources of this type of information - the Ship's Plan Index and the NAVORDSYSCOM ordnance drawings. The Ship's Plan Index (S.P.I.) is pre-prepared by the shipbuilding yard and is normally maintained aboard ship by the Engineering Office. The S.P.I. lists the wiring diagrams of fire control circuits, and the general arrangement and installation plans of the fire control equipment for your ship. The list does not include diagrams of the equipment's internal arrangements and electrical circuits. The NAVORDSYSCOM publications of ordnance drawings deal with the internal diagrams.

ORDNANCE DRAWINGS

A master list of drawings is prepared for each major piece of ordnance equipment. This list includes all components of the equipment. Each component is itemized by assemblies, subassemblies, and details on a separate list of drawing (LD).

The identifying number for each component LD is given, together with the general arrangement drawing number, on the master list of drawings for the equipment. Each component list of drawings also shows the special tools required for servicing that component. By reference to the list of drawings and the drawings for the mark and mod of a given assembly or subassembly, it is possible to work down to an individual part and to identify the correct nomenclature, drawing, piece number, design dimensions, tolerances, and all other necessary information.

How to read and interpret wiring diagrams and drawings is covered in the basic course, Blueprint Reading and Sketching, NavPers 10077-C.

ACCEPTANCE DATA

The ship's acceptance tests which were run when the equipment was installed, together with the factory acceptance test, constitute a criterion for evaluating subsequent tests and performance of the equipment. The ship's acceptance test results should be recorded so as to be available for convenient future reference.

SUPPLIES

Although the supply department is responsible for supplies, you need to know how to identify what you want to get, how to write out the request, and how to report on your use of the supplies. The publications containing the stock numbers are maintained in the supply department. Cooperation with supply personnel is essential in accomplishing your own duties.

SUPPLY DUTIES OF THE FTM

Small quantities of supplies are kept in the weapons department and within the divisions of the weapons department. These are usually frequently used small repair parts. As the materials are used, the FTM in charge of the supplies must make replacements. He has to know how to fill out the request form that he takes to the supply department to requisition supplies. These forms are illustrated and explained in Military Requirements for Petty Officer 3&2, NAVPERS 10056-C. The same text gives you information on sources of identification numbers for materials and spare parts. The Federal Stock Number (FSN) is the most important identification number. All the FSNs are given in the Federal Supply Catalogs, but you may not have to use those to look up a number because the FSN for your equipment is usually given in several other sources. One of these is the COSAL, also described and illustrated in the above text, although no ordnance or weapons sections are shown.

COSAL AND WHAT IT MEANS

The Coordinated Shipboard Allowance List (COSAL) is the list of all operating equipment and equipage aboard a particular ship. Although the segments of the COSAL illustrated in your military requirements text are not ordnance items (except some propellants in the alphabetical listings), they show you the format of the COSAL. The ordnance segment uses the same arrangement of information. It has three parts. Part 1 lists the ordnance equipment and the major components, and gives the component identification numbers. Part 2 lists the parts allowed for the ship. The quantity of each and the Federal Stock Number is given. Anything listed in Part 2 is available aboard ship. Part 3 of the COSAL is the final authorized on-board allowance quantity for a repair part. This is of most use to the Storekeeper. Items that are common to more than one department are totaled in this section. For example, a particular type of switch may be used in various applications on the ship. Part 3 of the COSAL will tell how many are to be on board and how many are allotted to each department. For a more detailed explanation of COSAL and how it is used, refer to Military Requirements for Petty Officer 3&2, NAVPERS 10056-C.

SOURCES OF ORDNANCE IDENTIFICATION

The publications most often used to identify ordnance material are:

1. The ordnance parts of the Federal Supply Catalog for identifying repair parts for requisitioning.
2. Illustrated Parts Breakdown of Ordnance Equipment (IPB). This publication is prepared by Ships Parts Control Center (SPCC). Each IPB is published for one particular type or piece of equipment, and describes and illustrates the relationship of all assemblies and parts comprising the equipment. IPB 0000 is an index of all IPBs.
3. Coordinated Shipboard Allowance List (COSAL), which was previously discussed.

One of the most important sources of identification is the information on nameplates. This may include the manufactures's name, make or model number, size, voltage, and like information. Identification publications such as manufacture's technical manuals may help you in identifying an item.

ORDNANCE IDENTIFICATION DATA

Ordnance identification data is important in identifying ordnance items. They should be used on all requests for material if the stock number is not available. This data includes:

The MARK NUMBER, which identifies the particular model of a certain type of ordnance equipment.

A MODIFICATION NUMBER (Mod), which indicates a modification of the basic mark number. Modifications are numbered serially, beginning with zero, for each separate mark.

An IDENTIFYING NUMBER, which is the number assigned to the blueprint plan of an ordnance component or assembly. It may be a drawing number, a list of drawing numbers (LD), a sketch number, or an assembly number.

A PIECE NUMBER, which is a subdivision of the drawing number and identifies by a serial designation every item appearing on a given drawing. Sometimes the drawing and piece numbers are stamped or etched on the part itself. Piece numbers are rarely used in later type ordnance assembly drawings. It is now standard practice that each item in a drawing will have its own separate drawing number.

A revision letter is often added to identify a particular revision of a drawing or list of drawings used in the manufacture of a part.

MANDATORY TURN-IN REPAIRABLES

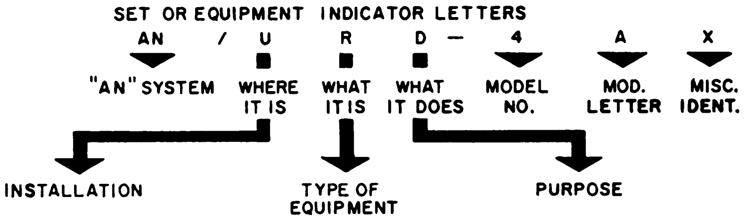
Since you will no doubt encounter the terms "mandatory turn-ins" and "repairables" in the process of obtaining replacement parts from supply, it will be helpful if you understand the purpose of the program and your responsibilities to it.

When any of your equipment fails, your primary concern is to locate the trouble, correct it, and get the equipment "back on the line." In most instances this involves tracing the trouble to a defective part, obtaining the replacement part from the supply storeroom and installing it, and throwing away the defective part. When the defective part is expensive and repairable, we encounter the repairables program.

A large number of parts can be economically repaired when they fail. This results in savings of dollars and time since it is quicker and cheaper to repair an item than to contract for and buy a new one — provided that the old item is promptly returned in repairable condition. For the program to work as intended, you and others have certain responsibilities. At the time your request for a mandatory turn-in item is presented to supply, they must inform you that the item is to be returned. At this point your responsibilities begin. You must:

- Remove the defective part without damaging it.

- Provide adequate protection to the part so that it will not be further damaged before it is turned in to supply. The most effective way,



A--AIRBORNE (INSTALLED AND OPERATED IN AIRCRAFT).
B--UNDERWATER MOBILE, SUBMARINE.
C--AIR TRANSPORTABLE (INACTIVATED, DO NOT USE).
D--PILOTLESS CARRIER.
F--FIXED.
G--GROUND, GENERAL GROUND USE (INCLUDES TWO OR MORE GROUND-TYPE INSTALLATIONS).
K--AMPHIBIOUS.
M--GROUND, MOBILE (INSTALLED AS OPERATING UNIT IN A VEHICLE WHICH HAS NO FUNCTION OTHER THAN TRANSPORTING THE EQUIPMENT).
P--PACK OR PORTABLE (ANIMAL OR MAN).
S--WATER SURFACE CRAFT.
T--GROUND, TRANSPORTABLE.
U--GENERAL UTILITY (INCLUDES TWO OR MORE GENERAL INSTALLATION CLASSES, AIRBORNE, SHIPBOARD, AND GROUND).
V--GROUND, VEHICULAR (INSTALLED IN VEHICLE DESIGNED FOR FUNCTIONS OTHER THAN CARRYING ELECTRONIC EQUIPMENT, ETC., SUCH AS TANKS).
W--WATER SURFACE AND UNDERWATER.

A--INVISIBLE LIGHT, HEAT RADIATION.
B--PIGEON.
C--CARRIER.
D--RADIAC.
E--NUPAC.
F--PHOTOGRAPHIC.[1]
G--TELEGRAPH OR TELETYPE.
I--INTERPHONE AND PUBLIC ADDRESS.
J--ELECTROMECHANICAL OR INERTIAL WIRE COVERED.
K--TELEMETERING.
L--COUNTERMEASURES.
M--METEOROLOGICAL.
N--SOUND IN AIR.
P--RADAR.
Q--SONAR AND UNDERWATER SOUND.
R--RADIO
S--SPECIAL TYPES, MAGNETIC, ETC., OR COMBINATIONS OF TYPES.
T--TELEPHONE (WIRE).
V--VISUAL AND VISIBLE LIGHT.
W--ARMAMENT (PECULIAR TO ARMAMENT, NOT OTHERWISE COVERED).
X--FACSIMILE OR TELEVISION.
Y--DATA PROCESSING.

A--AUXILIARY ASSEMBLIES (NOT COMPLETE OPERATING SETS USED WITH OR PART OF TWO OR MORE SETS OR SETS SERIES).
B--BOMBING.
C--COMMUNICATIONS (RECEIVING AND TRANSMITTING).
D--DIRECTION FINDER, RECONNAISSANCE, AND/OR SURVEILLANCE.
E--EJECTION AND/OR RELEASE.
G--FIRE-CONTROL OR SEARCHLIGHT DIRECTING.
H--RECORDING AND/OR REPRODUCING (GRAPHIC METEOROLOGICAL AND SOUND).
K--COMPUTING.
L--SEARCHLIGHT CONTROL (INACTIVATED, USE G).
M--MAINTENANCE AND TEST ASSEMBLIES (INCLUDING TOOLS).
N--NAVIGATIONAL AIDS (INCLUDING ALTIMETERS, BEACONS, COMPASSES, RACONS, DEPTH SOUNDING, APPROACH, AND LANDING).
P--REPRODUCING (INACTIVATED, DO NOT USE).
Q--SPECIAL, OR COMBINATION OF PURPOSES.
R--RECEIVING, PASSIVE DETECTING.
S--DETECTING AND/OR RANGE AND BEARING, SEARCH.
T--TRANSMITTING.
W--AUTOMATIC FLIGHT OR REMOTE CONTROL.
X--IDENTIFICATION AND RECOGNITION.

[1] NOT FOR US USE EXCEPT FOR ASSIGNING SUFFIX LETTERS TO PREVIOUSLY NOMENCLATURED ITEMS.

20.484

Figure 13-2.—AN system.

for all concerned, is to place the defective part in the same container in which you received the replacement part.

- Resist the temptation to cannibalize the part for components which you might possibly use sometime in the future.
- Return the defective part to supply as soon as practicable.

When the required part is not in the storeroom, supply must then take appropriate action to obtain it. The failed part must still be returned and should be turned in prior to receiving the replacement part. This way the failed part can enter the repair cycle and be available for reissue that much sooner. The only exception should be when the failed part will permit limited or reduced operation of an equipment until the replacement is received.

"AN" NOMENCLATURE SYSTEM

The AN nomenclature, figure 13-2, was designed so that a common designation could be used for Army, Navy, and Air Force equipment. The system indicator AN does not mean that the Army, Navy, and Air Force use the equipment, but means that the type number was assigned in the AN system.

AN nomenclature is assigned to complete sets of equipment and major components of military design; groups of articles of either commercial or military design which are grouped for military purposes; major articles of military design which are not part of or used with a set; and commercial articles when nomenclature will not faciliate military identification and/or procedures.

AN nomenclature is not assigned to articles cataloged commercially except as stated above; minor components of military design for which other adequate means of identification are available; small parts such as capacitors and resistors; and articles having other adequate identification in joint military specifications. Nomenclature assignments remain unchanged regardless of later changes in installation and/or application.

CHAPTER 14

TROUBLE ISOLATION AND GENERAL MAINTENANCE

INTRODUCTION

The effectiveness of your equipment depends largely upon the care and attention you give it. An improperly adjusted computer, for example, can reduce the accuracy of a perfectly aligned missile battery.

The work you perform on equipment falls into two broad categories: (1) actions you take to reduce or eliminate failure and prolong the useful life of your equipment, and (2) actions you take when a part or component has failed and the equipment is out of service. Therefore, we can think of the whole business of general maintenance as consisting of PREVENTIVE maintenance and CORRECTIVE maintenance.

In maintenance work of any type, you must use knowledge and skills of two fundamental kinds. First, you must have SPECIFIC information which applies only to the particular system or equipment which you may be called upon to repair or keep in good conidtion. Secondly, you must possess and use certain GENERAL skills and knowledge which apply to many kinds of equipment and to many types of work assignments.

The specific information required consists of special procedures and processes, and detailed step-by-step directions approved by the proper authority and recommended for a particular system or equipment. This detailed information is supplied in the system and equipment Ordnance Pamphlets (OPs) of the missile system you are assigned to.

Due to the complexity of Surface Missile System (SMS) equipment and the magnitude of SMS maintenance requirements, it would be impractical for this chapter to detail step-by-step procedures for specific maintenance actions. Besides, this information is readily available on Maintenance Requirement Cards. The mechanics of SMS maintenance procedures and trouble isolation will, however, be discussed. Many of the troubleshooting aids that have been developed will be highlighted so that you can take part in an effective maintenance program.

General maintenance techniques will also be discussed. Emphasis will be placed on those skills and procedures which are applicable in all shipboard maintenance programs. The general maintenance skills and procedures are based on knowledge which is not contained in system or equipment OP's but must be learned on the job and from rate training manuals.

The final part of this chapter will be devoted to maintenance safety precautions. Again, the discussion will be of a general nature. As you know, specific safety precautions are listed on every Maintenance Requirement Card where there is a possibility of hazardous conditions developing.

PREVENTIVE MAINTENANCE

Maintenance performed to prevent the likelihood of future troubles or malfunctions is usually referred to as preventive maintenance. This form of maintenance consists mainly of visual checks of the equipment prior to and during operation, cleaning the equipment, and the various components therein, lubricating, and the periodic inspections.

Visual Checks

Equipment should be checked visually for loose leads, improper connections, damaged or broken components, etc., prior to applying power to the equipment. This applies particularly to new equipment, equipment returned from overhaul, equipment which has been preserved or stored for long periods of time, and equipment which has been exposed to the weather. A close visual inspection should also be conducted on O-rings, gaskets, and other type seals when the equipment under check is a pressurized component. This visual inspection will often reveal discrepancies that may be corrected at that time with a minimum amount of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

Cleaning

Cleaning the equipment and the various components consists of removing dust, grease, and other foreign matter from the covers, chassis, and operating parts. This includes the removal of corrosion, fungus, and all other types of matter which could cause operating failure of the equipment. The methods used to clean the various parts and units will vary, but usually a vacuum cleaner is used to remove the loose dust and foreign matter. The remainder is then wiped or removed with a clean lint-free cloth.

If it is necessary to remove grease or other petroleum deposits, the cloth may be moistened with alcohol or drycleaning solvent. After removing the grease, the part should be wiped dry, or allowed to dry by evaporation prior to applying power.

Lubrication

Lubrication of electronic equipment consists of lubricating the mechanical parts which are associated with the electronic equipment. Equipment which may need periodic lubrication, such as unsealed bearings, antenna drives, waveguide rotating joints, etc., should be lubricated as directed by the equipment's Maintenance Instructions Manual. The specification number of a lubricant should be strictly followed, as the viscosity of a lubricant will change with a change in operating temperature. High operating temperatures cause lubricants to become thin, while low operating temperatures cause lubricants to thicken.

CORRECTIVE MAINTENANCE

When defective parts or unsatisfactory operation have been revealed, it is necessary to analyze the equipment, find the defective part or parts, and make the appropriate replacement or repair. In general, the most effective method for this analysis is a careful and logical step-by-step troubleshooting procedure.

BASIC MAINTENANCE PROGRAM

Preventive maintenance, then, consists of the care, upkeep, and minor repairs and adjustments performed by the technician to ensure the best condition of his equipment and to reduce the chance of sudden equipment failure or malfunction. Preventive maintenance aboard SMS ships is accomplished by means of scheduled system and equipment performance tests, scheduled servicing procedures, and careful observation of system/equipment performance during periods of operation.

When preventive maintenance or performance checks reveal that a casualty or malfunction exists in a system or equipment, some form of corrective maintenance includes those actions required to restore fire control equipment to its designed capabilities or efficiency. This includes the repair of damage caused by wear, accident, or other cause.

PLANNED MAINTENANCE

Planned maintenance is based on the principle that readiness can be determined through testing, and thoroughness can be assured by proper scheduling. This maintenance program is known as the Planned Maintenance System/Surface Missile Systems (PMS/SMS), and is incorporated in your Weapons System OP's and equipment OP's.

SYSTEM UPKEEP

Some maintenance tests are conducted on a system level, and if a fault appears, PMS/SMS troubleshooting material provides a means for spanning the gap from test to a positive and rapid identification of the individual equipment causing the trouble.

PMS/SMS also provides rapid procedures for locating faults in the system and recommends methods and procedures for necessary corrective maintenance. PMS/SMS is designed so that highly skilled, experienced technicians can share the workload with lesser skilled personnel. Along with this, it has established that important tasks be grouped as scheduled maintenance events.

To see the value of system level testing, let's suppose that a misalignment exists between two sets of equipment such as the search and fire control radars. Individual equipment tests would probably indicate that both radars were operating satisfactorily. In actual operation, however, the fire control radar would be unable to acquire the targets disclosed by the search radar due to the misalignment. System level testing, however, would consider one equipment's performance with respect to another's and provide you with the means of determining the alignment problem.

Those individual circuits and system modes which cannot be conveniently checked in the DSOT are evaluated by conducting supplemental system ests and equipment tests. These, plus the standard servicing procedures, are also listed as scheduled maintenance events. PMS/SMS requires he scheduling of these test and maintenance asks into the ship's operating schedule according o an established management plan. Scheduled ests of all elements of missile systems are conducted often enough to assure acceptable performance, and yet no more often than necessary. Requirements for test frequencies have been designed for the minimum testing which s statistically necessary for material readiness. The PMS/SMS philosophy has eliminated overtesting, has substantially relieved the excess workload imposed on technical personnel, nd reduced unnecessary wear on equipment. The predetermined frequencies of testing and ther maintenance tasks have been prepared in ccordance with CNO's Planned Maintenance ystem. These schedules are an integral part f the Planned Maintenance System.

The maintenance events are arranged by the hip's Weapons Officer to fit the ship's operating rogram. This allows the appropriate mainenance procedures to be continued whether the hip is at the dock or at sea. The primary reason or conducting the tests is to determine the operability of the weapons system. If a response hould indicate a fault which prevents the system rom operating at the required degree of comat readiness, PMS/SMS troubleshoooting documents are consulted. These documents are loated by keys in the test procedures, and will ot only lead to the exact location of trouble in the shortest possible time but they will also pecify the corrective measures. The documents represent the most advanced methods of missile system troubleshooting techniques.

QUIPMENT UPKEEP

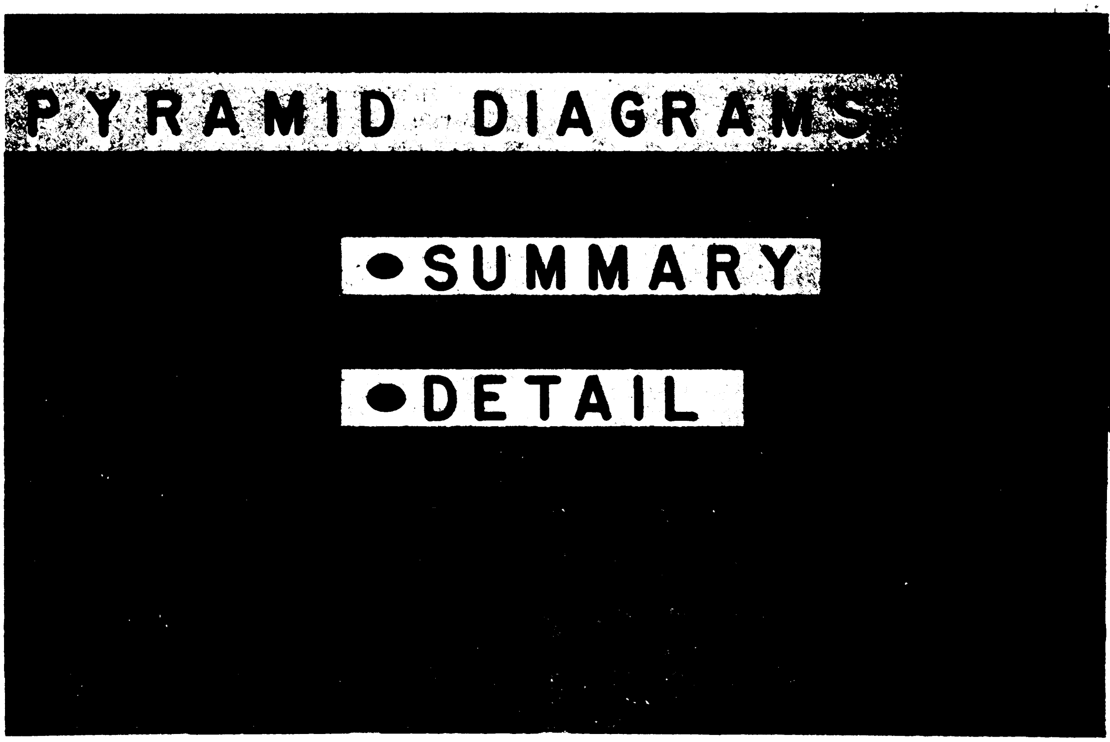
The equipment level maintenance tests are ontained in the equipment PMS/SMS OP's. There is a separate OP for each major equipment. It contains equipment description and operating procedures, PMS/SMS scheduled or preventive maintenance, maintenance turn-on procedures and the equipment troubleshooting material. These equipment OP's have been specifically created as part of PMS/SMS to quickly isolate items of faulty equipment. Direct referral to the troubleshooting section is from system fault directories and diagrams and from the equipment turn-on procedures and troubleshooting index.

Equipment troubleshooting aids include both summary and detailed pyramids (fig. 14-1). These pyramids are a display of an output function from output to source. The primary pyramid is a condensed version which is prepared to provide guidance when an unusually large or complex detailed pyramid is required. Signal flow diagrams (fig. 14-2) aid in equipment troubleshooting by displaying module to module functions from output to source. They show all testable points with values and tolerances plus adjustable components and appropriate notes for use. Relay ladder diagrams (fig. 14-3) show an arrangement of relay coils which display the energizing path from the energizing voltage to common return with all switches, terminal connections, and contacts to other relays in the path. Power distribution diagrams (fig. 14-4) are used to locate power failure and trace it to a specific circuit element. These diagrams illustrate the chassis-to-chassis distribution of each internally developed voltage back to the primary voltage interface.

All of these troubleshooting aids may be used jointly with the actual schematic drawing to trace and correct faulty equipment affecting overall performance.

EQUIPMENT MAINTENANCE

Even though you, as an FTM 3 or FTM 2, will be an active participant in system maintenance procedures, your participation will normally be limited to the equipment area to which you are assigned. Therefore, it is mandatory that you become familiar with the details of equipment maintenance procedures. You will study maintenance procedures, at the systems level, when you are preparing yourself for first class and chief.



PYRAMID DIAGRAMS

- SUMMARY
- DETAIL

167.144

Figure 14-1.— Pyramid diagrams.

TROUBLE ISOLATION

You equipment OP contains the following maintenance troubleshooting documents:

1. Troubleshooting index
2. Maintenance turn-on procedure
3. Signal flow diagrams
4. Summary and detail pyramids
5. Relay ladder diagrams
6. Power distribution diagrams
7. Schematic diagrams

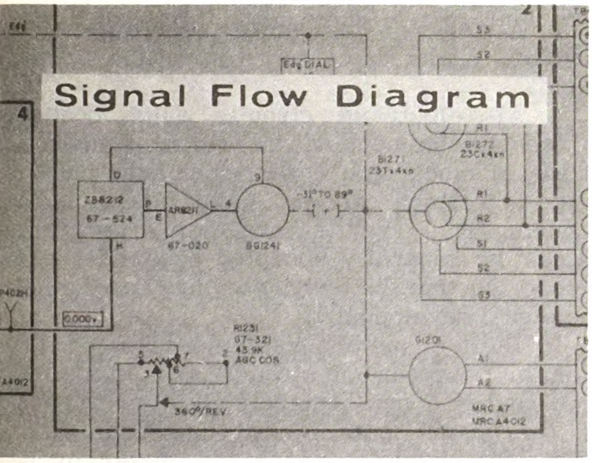
These documents will provide you with the detailed step-by-step procedures that you will follow when isolating a casualty to a specific component or an area within the equipment.

Troubleshooting Index

The Troubleshooting Index contains an alphabetical listing of the equipment outputs cross indexed to an associated signal flow diagram, pyramid diagram, or other reference diagram.

An equipment output is defined as any output signal from the equipment to all [illegible] equipment of the fire control system. For [illegible] equipment, this will include the inputs to [illegible] control console displays and transmitter [illegible] (radiated RF energy). Where appropria[illegible] control symbols are listed for [illegible] equipment outputs.

If you observe an equipment ma[illegible] during normal individual equipment op[illegible] you can use the troubleshooting index [illegible] sociate the malfunction with a particular [illegible] ment output. After you have determined [illegible] correct output function, the troubleshooting index will refer you to the appropriate troubleshooting document, signal flow diagrams, pyramid, etc.



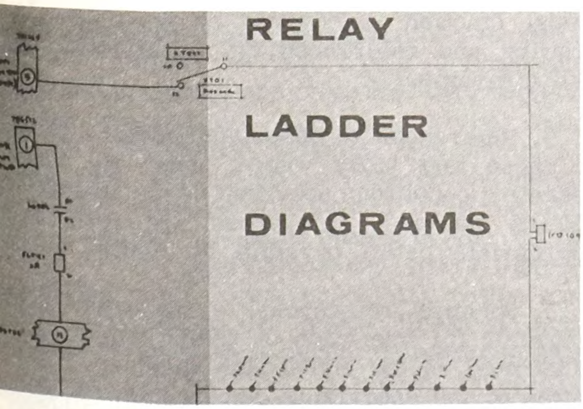
167.145
Figure 14-2.—Signal flow diagrams.

In a few instances, you may not be able to sociate the malfunction with an equipment out- t. If not, you will have to scan the pyramid agrams to find the applicable diagram. As u gain experience in the use of the pyramid agrams, you will become familiar with the cation of the various functional groups on the agrams.

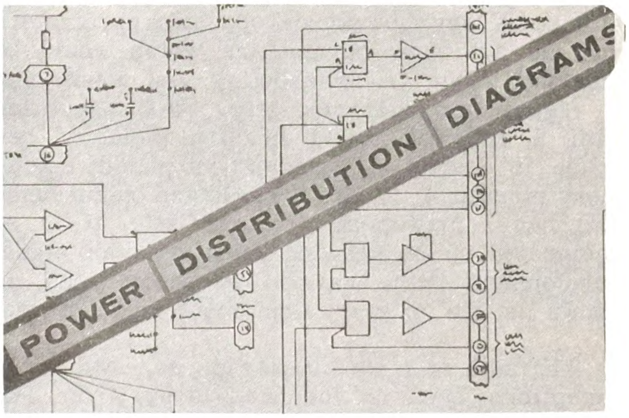
intenance Turn-On Procedure

The maintenance turn-on procedure is a tailed and illustrated step-by-step procedure for energizing an equipment from a power-off condition through operate. The procedure outlines a recommended turn-on technique whereby a systematic evaluation of all below decks monitoring devices which are indicative of equipment operability (indicator lamps, panel meters, fuse indicators, etc.) is made by visual monitoring at a time and in a sequence which is intended to:

1. Pinpoint improper equipment operation to specified functions rather than general failures.
2. Make the most efficient and effective utilization of the equipment operator "Wait Time" which must be expended because of built-in equipment time delays; e.g., Off-Standby and Standby-Operate.



167.146
Figure 14-3.—Relay ladder diagrams.



167.147
Figure 14-4.—Power distribution diagrams.

During the turn-on, all below deck indicator readings and switch positions are specified. The procedure text is supported by illustrated photographs which show the location of each indicator and switch.

It is recommended that equipment operators become familiar with the maintenance turn-on procedure and that the procedure be used:

1. Whenever the equipment is turned on, or energized from a lower to higher level of operability; e.g., Standby to Operate.

2. As a training aid for new operators.

3. As an operator/technician troubleshooting aid for localization of on-line or off-line equipment failures to offending functions and as a key-in to the appropriate troubleshooting document.

Signal Flow Diagrams

Signal flow diagrams are schematic-block diagram type drawings which collectively depict the function/circuit relationship of all equipment outputs to the weapon system. For radar equipment, this will include outputs (scope displays) to the operator and outputs (RF transmissions) to the selected target. These drawings are intended for use as training aids as well as troubleshooting documents. All signal flow diagrams are drawn for a specified dynamic operating condition, e.g., guidance mode. These conditions are outlined under the heading GENERAL NOTES, on page one of each drawing. All subfunction specifications conform to these dynamic conditions. The signal flow diagrams are somewhat limited in their use as troubleshooting aids since they show normal operation parameters and do not show parameters which would be obtained under troubleshooting test conditions.

Signal flow diagrams (fig. 14-2) are titled with a selected output function (selected because it covers the greatest amount of equipment circuitry). Where the selected output function has a multimode characteristic, it is so designated in the drawing title. The main signal development path, outlined by heavy lines, is shown in the primary equipment mode of use.

The path of main signal flow is, with minor exceptions such as feedback loops, from left to right on each drawing page with the primary output appearing at the right edge of page one. Auxiliary outputs appear near the right edge of the page on which their interface circuitry is shown. The signal flow path is shown to equipment output interface on page one from equipment input interface or source circuit.

The signal flow diagrams contain the following types of circuitry which develop the equipment output:

1. All cabling and sliprings through which primary and supporting signals flow.

2. Terminal boards, standoffs, and other tie points.

3. Relay contacts, designated by contact numbers, relay number and relay coil energizing voltage source or bus name. All relay contacts are shown in their deenergized state. Reference should be made to the relay ladder diagram to trace out energization paths of relay coils not shown.

4. All coils of relays which are energized by signal flow.

5. All chassis test jacks, designated by jack number, signal name and a specified tolerance value.

6. All electrical circuits which contribute to the development of the output function are shown in block type boxes which have functional titles and which call out major electrical components. The circuits have been organized and named by generally accepted equipment terminology, so that the technician may readily follow the signal development.

7. Built-in meters and lamp indicators which monitor operation of circuits are illustrated by appropriate circuit symbols above or to the side of the signal path. An arrow designates the electrical point at which the meter or lamp indicator is monitoring circuit operation. In some cases, meter and lamp circuits are shown directly on signal flow diagrams.

8. All adjustments of potentiometers, tunable coils, capacitors, etc., which affect the signal being traced.

9. Miscellaneous components-resistors, capacitors, etc., which cannot be functionally grouped as in item 6, but are essential to signal development, are shown.

All circuits which affect the signal being traced and which are not shown on the signal flow diagram are referenced to drawings on which they are illustrated in detail. This cross-referencing includes:

1. References to power distribution diagrams.

2. References to other signal flow diagrams. Circuitry which is common to more than one output function is covered on one signal flow drawing and referenced on all affected signal flow diagrams.

3. References to associated detail pyramids. At those test jacks where, under the dynamic operating conditions specified no meaningful data can be obtained, references are made to the appropriate detail pyramid by figure number.

4. Specific references to the relay ladder diagrams for operation of relays which are not illustrated on the signal flow diagram. The location of the energizing circuit path for relays may be found by locating the relay in the relay ladder index using the relay number and unit designation shown on the signal flow diagram.

Use of Signal Flow Diagrams. Signal flow iagrams are especially useful in tracking sig- il continuity between functional circuits. The omplete signal path is traced on one diagram rough below-deck and above-deck cabling, iprings, cabinet backboards, connectors, and ndividual units. This characteristic of signal ow diagrams makes them useful in trouble- ooting power supply overloads, open inter- cks, cable failures, and loose connections.

The signal flow diagrams are the only docu- ents which depict the complete functional cir- iitry from source to output of those equipment itputs which utilize only a few relatively simple rcuits for their development. No pyramid dia- rams were generated for these outputs and e signal flow diagrams should be used for oubleshooting this type of circuit.

Properly used by personnel with a knowledge the basic equipment operational principles, e signal flow diagrams are a valuable ref- ence in understanding the functional operation the equipment.

ramid Diagrams

Pyramid diagrams (fig. 14-1) are trouble- ooting tools which enable the technician to ice an equipment malfunction by starting with equipment output and progressively testing e subordinate functions which produce the uipment output. Each pyramid diagram con- sts of a set of tests arranged by functional pendency. The tests are contained in boxes d the boxes are connected by lines which licate their functional dependency. Within each k is the complete information required to de- rmine a GO or NO-GO condition of a function. ere the number of test boxes is large and ny drawing sheets are required, the complete ctional dependency arrangement has been wn on a summary pyramid. The summary ramid also serves as an index to the detail ramid by outlining with dotted lines the test es contained on each sheet of the detail ramid. Where applicable, any visual indica- ns, called quick-looks, associated with a test are highlighted by heavy lines on both summary and detail pyramid diagrams. The rangement of the test boxes by functional endency and the troubleshooting method as- iated with the pyramid diagrams provides a ible yet complete troubleshooting procedure. ce each major equipment output has a separate pyramid diagram, the proper diagram can be quickly located. The "quick-look" feature provides rapid evaluation of those visual indications which pertain to the particular output. A NO-GO indication in a "quick-look" will give the technician rapid entry to a particular part of the pyramid diagram. As troubleshooting progresses, the experienced technician will be able to select the most likely of the several tests to perform from his observations of the previous test results. The less experienced technician will have presented to him all the tests he should perform to locate the malfunction.

The technician should use the summary pyramid diagram as an entry to the detail pyramid diagram. Troubleshooting begins by setting the equipment to the conditions specified in the summary pyramid notes. These are the equipment conditions necessary for the "quick-looks" to be applicable. Entry to the detail pyramid diagram is made at the lowest level NO-GO "quick-look" indication. Where all "quick-look" indications are GO, entry is made at the apex box of the detail pyramid diagram.

The general method of troubleshooting associated with the detail pyramid diagram is one of successive testing from output to input. Testing proceeds by starting at the top of the diagram with the test described in the apex box, or at the entry box determined from the summary pyramid. A NO-GO test result requires performance of the tests in those boxes below and connected to the apex or entry box. When a NO-GO test result is obtained on that level, the technician proceeds at once to the next level of boxes connected beneath the NO-GO box. When GO test results are obtained in all boxes below a NO-GO box, the trouble has been isolated.

There are two types of notes appearing on the apron area of each detail pyramid diagram: GENERAL and SPECIFIC. The general notes specify (1) the general operational conditions to which the equipment must be set to utilize the diagram as a troubleshooting tool, (2) the test equipment used in performing the pyramid box tests, and (3) any other instructions which are generally applicable to all pyramids and/or to the particular pyramid diagram. The test equipment is listed for the technician's convenience so that he may assemble his equipment and have it readily available as it is needed. The other general notes employed are self-explanatory.

The specific notes are referred to in individual test boxes and explain detail test setup conditions and measurement techniques. The notes required on a particular pyramid page appear on that page, unless two pages of notes are required to support one pyramid page.

The following paragraphs describe in detail the information contained within each test box and how it is to be used. The material in the test box appears in the following listed order:

TITLE—The colloquial name of the function being tested.

NUMBER—A number is assigned to each box to facilitate cross-referencing between sheets, to other pyramids, and from other PMS/SMS documents.

SAFETY NOTES—Where personnel safety may be endangered through performance of the test, the word WARNING appears at the top center of the box immediately under the title. If equipment safety may be endangered, the word CAUTION is inserted at the same location. Whenever this occurs, it is expected that the technician will perform the test with care and as instructed.

SETUP CONDITIONS—This material contains specific, step-by-step information for the performance of the test. Where the information in the general notes is sufficient, no additional information is included in this section. The information in the general notes always applies to each test, except as modified by the specific test setups in each box.

TEST EQUIPMENT—The test equipment that is required to perform the test is called out by common name; e.g., SPM-5, multimeter, recorder. The specific piece of test equipment with full nomenclature, model, etc., is called out in the general notes. In addition, when an oscilloscope is to be employed, the following setup data is supplied.

1. Whether scope is to be synchronized internally or externally.

2. Polarity of synchronization.

3. Location of sync signal by jack number, signal name, unit common name, and unit designation number.

EXAMPLE: "Oscilloscope, external sync (+) at JO8, WIDE GATE, on wide gate amplifier, UD61."

MEASURE AT—The location of the test points at which measurements are to be made by jack number, signal name, unit common name, and unit designation number.

VALUE—The value which should be observed on the measuring test equipment with appropriate tolerances within which the function is considered operative. The tolerances specified include the tolerance of the test equipment being used.

REFERENCES—These include references to MR card procedures, signal flow diagram, the relay ladder diagram, power distribution drawings, and circuits shown on unit schematics. The component references are to be used when the malfunction has been isolated to the particular test box. This accomplished when the test in a particular box is NO-GO and all test in boxes connected beneath that box are GO.

QUICK-LOOK—The quick-looks should be checked as the first step in the use of the pyramid diagram. The quick-looks provide rapid trouble isolation to lower levels of the pyramid diagram. Quick-look features are included in those cases where the functional circuitry represented by the functional test box is also monitored by a built-in test meter, or lamp indicator. The monitoring device is denoted by a heavy bordered box encompassing the lower portion of the test box. The data contained within the box identifies the readout by panel name, schematic symbol, chassis common name, and unit designation number, and specifies the value which the readout should indicate. In some cases, test boxes containing automatic readouts also contain a second test using external test equipment. This is due to one or more of the following:

1. The monitoring device is not accurate enough; e.g., allowable tolerances are ±1%, automatic readout is a ±5% indicating device.

2. The monitoring device does not comprehensively monitor the function; e.g., it monitors voltage, and both voltage and pulse shape must be evaluated.

Relay Ladder Diagram

The relay ladder diagram is comprised of two parts: the indexes and the relay schematic sheets (fig. 14-3).

The indexes list in unit designation sequence all relay coils and related switches and indicator lamps in the radar and cross-indexes by figure, sheet, and zone the location of the relay coil and indicator lamp energizing path. The functional types of relays used in the radar and ie documentation under which their energizing aths are covered are as follows:

1. Signal Operated Relays—Signal Flow iagrams,
2. All Other Relays—Relay Ladder Diagram.

The relay ladder sheets trace the energizing ath for the relay coil or indicator lamp from a ommon interface point appearing on both a ower distribution diagram and the ladder sheet, ırough the equipment, to the respective relay oil or indicator lamp, to a common return ower interface. The relay ladder sheets show ll cabling, terminal connections, relay conıcts, switches, and lamps in the enerizing path.

The relay ladder diagram is intended for use s a support troubleshooting document for detail yramids, signal flow diagrams, and the mainenance turn-on procedure. It is also to be used s the primary troubleshooting document for all quipment switching problems.

ower Distribution Diagrams

Power distribution diagrams (fig. 14-4) are ıpport troubleshooting diagrams for signal flow iagrams, detail pyramid diagrams, the relay adder diagram, and the maintenance turn-on rocedure. Specific references to the power istribution diagrams are made in the foreıentioned material for purposes of (1) comleting the functional circuitry associated with pecific equipment output functions, and (2) troule isolation of equipment power failures.

All power distribution diagrams available for oubleshooting are contained in the equipment P. All of the diagrams are indexed for the echnician's convenience in the table of contents. ach diagram illustrates the distribution of ower from the power source to the cabinets nd chassis of the equipment showing all interediate terminal boards and cable connections.

chematic Diagrams

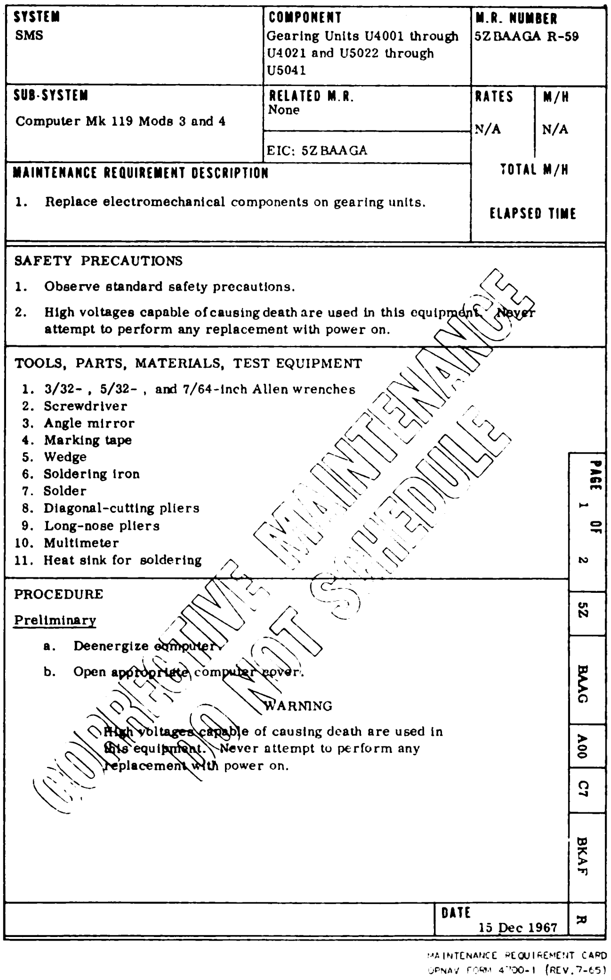
Schematic diagrams are also in your equipment P. A schematic diagram shows how the parts a circuit are connected for the operation the equipment. It does not tell how the parts ok or how they are constructed. Each comonent is illustrated by. a symbol. A set of hematics enables the technician to trace the assage of energy throughout the entire equipent. The detail of each circuit is drawn.

PMS/SMS trouble isolation procedures will reference the appropriate schematic diagram when there is need for detailed circuit information.

CORRECTIVE MAINTENANCE (MRC)

Alignment/adjustment (A) and repair/replacement (R) procedures are shown in MRC format (fig. 14-5).

The MR cards are not used as a scheduled event. They are designed for use in corrective maintenance actions. The technician is keyed to the use of the alignment/adjustment procedures



SYSTEM SMS	**COMPONENT** Gearing Units U4001 through U4021 and U5022 through U5041	**M.R. NUMBER** 5Z BAAGA R-59	
SUB-SYSTEM Computer Mk 119 Mods 3 and 4	**RELATED M.R.** None EIC: 5Z BAAGA	**RATES** N/A	**M/H** N/A
MAINTENANCE REQUIREMENT DESCRIPTION 1. Replace electromechanical components on gearing units.		**TOTAL M/H** **ELAPSED TIME**	

SAFETY PRECAUTIONS

1. Observe standard safety precautions.
2. High voltages capable of causing death are used in this equipment. Never attempt to perform any replacement with power on.

TOOLS, PARTS, MATERIALS, TEST EQUIPMENT

1. 3/32- , 5/32- , and 7/64-inch Allen wrenches
2. Screwdriver
3. Angle mirror
4. Marking tape
5. Wedge
6. Soldering iron
7. Solder
8. Diagonal-cutting pliers
9. Long-nose pliers
10. Multimeter
11. Heat sink for soldering

PROCEDURE

Preliminary

a. Deenergize computer.

b. Open appropriate computer cover.

WARNING

High voltages capable of causing death are used in this equipment. Never attempt to perform any replacement with power on.

CORRECTIVE MAINTENANCE
DO NOT SCHEDULE

PAGE 1 OF 2 | 5Z | BAAG | A00 | C7 | BKAF | R

DATE 15 Dec 1967

MAINTENANCE REQUIREMENT CARD
OPNAV FORM 4700-1 (REV.7-65)

98.176

Figure 14-5.—Corrective Maintenance Requirement Card.

through specific references on detail pyramids and from references in other procedures. The repair/replacement procedures are to be referred to by the technician whenever repair or replacement of spare assemblies and components is required.

Alignment/Adjustment

The MRC A-procedures are intended for use as support documentation for signal flow diagrams, detail pyramids, the maintenance turn-on procedure, MRC R-procedures, and MRC equipment test procedures. Collectively the procedures comprise all of the equipment level alignment/adjustment and calibration procedures required for the equipment.

Within each series, the procedures have been assigned numbers in ascending numerical order (e.g., A-1, A-2, A-3, etc.). It is important to note that the numbers assigned are for indexing and cross-referencing purposes only and have no other significance. That is, a complete alignment of a subsystem cannot be performed by following the alignment procedures within a series in ascending numerical order. To accomplish this task, it is necessary to refer to the associated detail pyramid or pyramids, as may be the case, and perform the procedures in functional dependency input to output sequence as references therein.

An additional and highly important function of the MRC A-series procedures is their use in obtaining the established values referred to on detail pyramid and signal flow diagrams. The established values are tabulated alphabetically in a table. Established values fall into two categories. One category is comprised of those parameters of the equipment which have wide sign tolerances as applied to all equipment of a particular type, but which under conditions of peak operating performance, have specific values, with much tighter tolerances, unique to each equipment. Category two is comprised of those parameters whose values are a function of the mechanical tolerances peculiar to each equipment and the installation site of each equipment.

Procedures for obtaining the established values are specified in the table of established values. The procedures are performed and the values recorded when the equipment is operating at peak performance, and are used thereafter as reference values to facilitate the evaluation of equipment performance.

Repair/Replacement

Under the PMS/SMS concept, units and assemblies which are spared or which contain spared components require MRC coverage if the repair procedure is not obvious upon inspection. Each MRC procedure in the series has been assigned a sequential reference number. As with A-series procedures, the numbers assigned are for indexing and cross-referencing purposes only.

To facilitate use of the MRC R-series procedures, road map diagrams (fig. 14-6) are presented for the above-deck and below-deck equipment. These diagrams illustrate the methods by which the various subassemblies may be removed and replaced. Each unit assembly shown on the road maps is identified by common name, unit designation number, or symbol designation number. By referring to the road maps, the technician can determine those units assemblies that must be removed to perform a given task. Then by selecting the procedures applicable, the full task may be accomplished without unnecessary steps. On the road map diagrams, solid lines indicate the removal of a unit/assembly by the process that involves the least amount of equipment disassembly. Dashed lines indicate alternate removal procedures. For example, in figure 14-6, to remove unit C, unit B must be

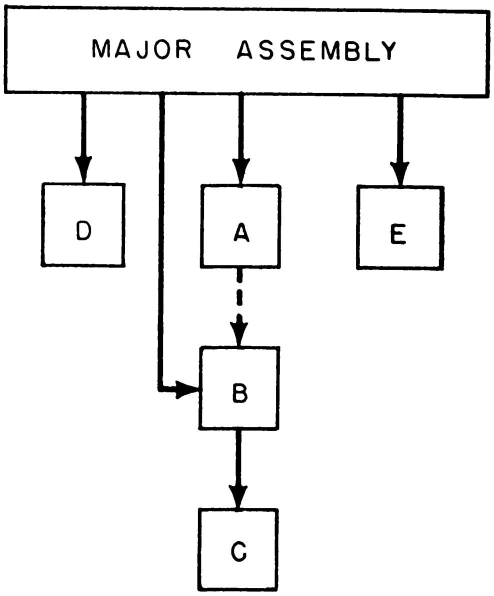


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Figure 14-6.—Typical road map block diagram.

emoved first; this is shown by the solid line etween B and C. The broken line between A and indicates the alternate procedure that could e used in removing A, B, and C in sequence. f only unit B is to be removed, the solid line etween B and the major assembly indicates hat B can be removed without removing unit A.

TROUBLESHOOTING

Much of the Fire Control Technician's time s spent troubleshooting the equipment to which e is assigned. Your job may be to maintain a reat number of units within the fire control ystem, many of which are quite complex, and hich might seem at a glance beyond your bility to maintain. However, the most complex b usually becomes much simpler if it is first roken into successive steps. Any maintenance b should be performed in the following order:

1. Analyze the symptom.
2. Detect and isolate the trouble.
3. Correct the trouble and test the work.

ROCEDURES

In troubleshooting, as in most other things, ere is no substitute for common sense.

If there is no input power present to the uipment, it may be assumed (temporarily) that e equipment is not defective. Check all ap- icable switch positions, circuit breakers, fuses, c., then check for power at the bus which eds the equipment. Check the tightness and ysical condition of interconnecting cables. ing the wiring diagrams in the OP's, check at ccessive tie points and splices for continuity, ort circuits, or grounds. The procedures to be lowed with these tests were discussed in apter 12, General Purpose Test Equipment.

If a circuit breaker is tripped or if a fuse blown, a circuit malfunction is indicated. wer to the circuit containing the "open" should turned off, and should not be reapplied until the lfunction is located and corrected. The most nmon causes of tripped or blown circuit pro- tors are short circuits, faulty grounds, or rload conditions. However, circuit protectors netimes fail due simply to age or to transient ditions. If, after a thorough check, no ap- ent reason for the failure can be found, the aker may be reset or the fuse replaced with proper size and type, and the power reap- d. If the protector fails again, a malfunction definitely indicated.

If the analysis does not indicate the existence of a short circuit, faulty ground, or overload condition, but the equipment still does not operate, continue to take measurements with power applied. These measurements should be taken systematically at progressive checkpoints. Particular faults which may interrupt current through a circuit include broken wiring, loose or faulty terminal or plug connections, faulty relays or switches, and uncoupled splices. Be alert for these conditions.

If the defective unit cannot be identified while still installed in the equipment, it may be advisable to turn off the power and substitute units one at a time with units which are known to operate properly. As each unit is replaced, power should be reapplied and the system checked for operation or for symptoms of nonoperation. If the system operates normally, the faulty unit has been identified, and the faulty unit may be taken to the shop for corrective maintenance. At this stage of the overall maintenance process, it is also advisable to try to determine the reason for the failure of the unit—it is conceivable that the new unit may also be damaged if the basic cause is not corrected.

Following removal of the defective unit and the subsequent analysis, all other items of the original installation should be reinstalled and safety wired, and an operational check performed. During the operational check, any readjustments or calibrations should be accomplished as required.

SIGNAL TRACING

Signal tracing is a very effective method for locating defective stages in many types of electronic equipment. It is especially useful when servicing equipment which normally contains no built-in meters. The signals are checked at various points in the equipment, unit, or circuit using test instruments such as vacuum tube voltmeters, oscilloscopes, or any high impedance instrument which is appropriate. The test instrument should have high impedance so that it will not change the operation of the circuit to which it is applied.

When using the signal tracing technique to measure a.c. signals, be sure that the test instruments are adequately isolated from any d.c. potentials present in the circuit. Some test instruments are equipped with special a.c. probes which incorporate a capacitor in series with the input; other equipment is not so equipped. Before using any item of test equipment, the technician must familiarize himself with the characteristics and proper use of the test equipment, as well as with the equipment under test.

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any abnormal effect can be localized.

TEST PROBE SUBSTITUTION

Using a test equipment probe with equipment other than that for which it was designed may result in considerable error. Any differences in the internal resistance of the probe and input circuitry of the equipment precludes substitution without calibration. For example, the internal resistance of a 10:1 probe is, in most cases, nine times higher than the input circuitry of the equipment. It should be noted that 2:1, 50:1, and 100:1 probes are available as well as 10:1 probes.

Test probes which are not recommended for specific equipment should not be used, because they may not have sufficient capacitive adjustment to preserve the waveshape of the observed signal. A sound rule is to use all test probes only with the equipment for which they were designed.

DEFECTIVE COMPONENTS

Should it become necessary to replace a part with a substitute, you must make sure that the substitute part is a proper replacement. With resistors, for instance, several characteristics must be considered—ohmic value, wattage rating, tolerance, physical size, and type construction. Capacitors involve consideration of physical size, capacity, tolerance, temperature coefficient, and voltage rating. Plugs and connectors will almost invariably have to be exactly as prescribed since it is difficult to find items of this type that are interchangeable.

Basic Electronics, NAVPERS 10087-C, contains information on color codes for capacitors and resistors. Refer to this manual for standard codes, specifications, physical shapes, methods of reading, and tolerances.

CHECKING AFTER REPAIR

No repair job is complete until the repaired component or unit is reinstalled and actually operating properly. After the faulty component has been replaced and/or the unit reassembled, dust and shield covers have to be replaced. Often a shield or plate that has been installed will touch a bare wire or other contact and will render the component or unit inoperative or cause substandard operation.

After the component or unit is reinstalled in the equipment and properly secured, it must be given a final operational test. The most important test is an operational check under operating conditions. When the component or unit performs properly in the equipment and is securely mounted, the casualty has been repaired.

The troubleshooting steps described in the preceding paragraphs are summarized in figure 14-7, which shows in chart form a general troubleshooting procedure. The directions given in blocks 1 through 5 are steps to be used in locating trouble, and the directions given in blocks 6 and 7 are steps in repairing the equipment. (Steps 2, 3, 4 and/or 5 may sometimes be eliminated, but steps 6 and 7 will always be followed.)

REPAIR TECHNIQUES

SOLDERING

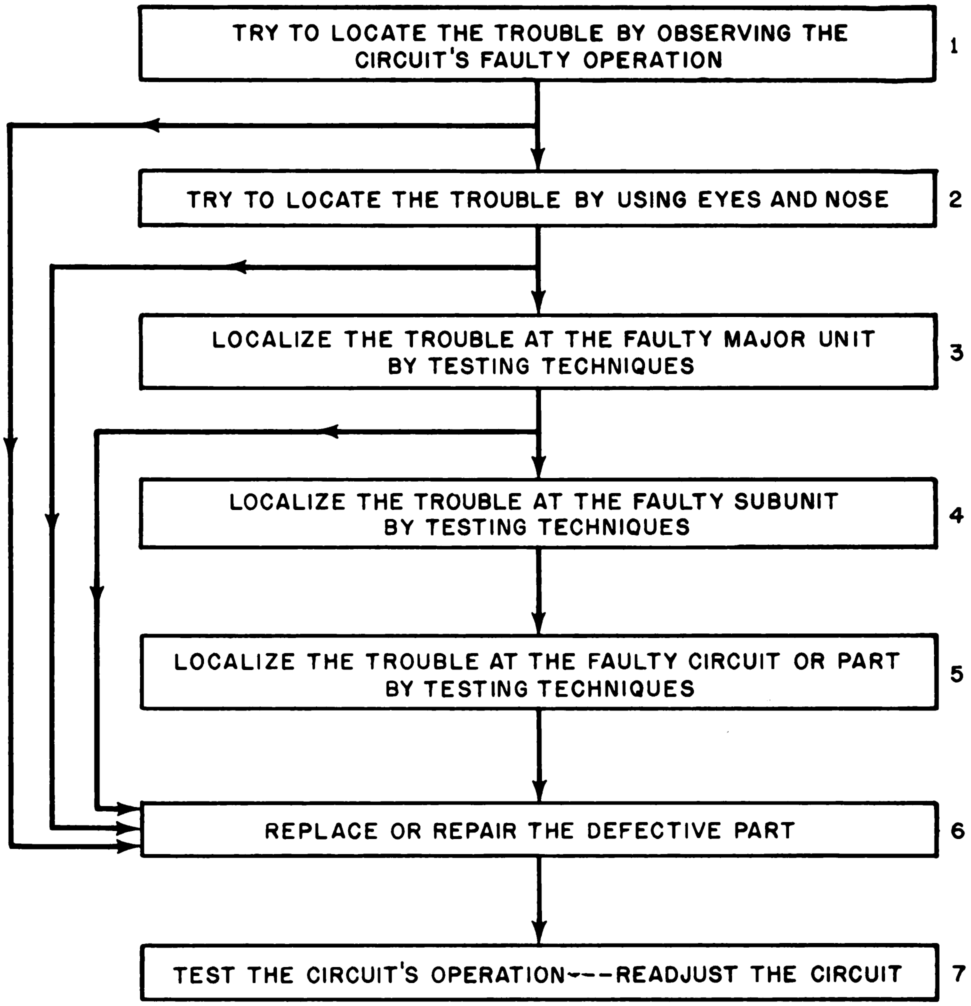
The correct procedure for soldering is given in Basic Electricity, NAVPERS 10086-B; therefore, it will not be covered here. Let us consider for a moment the end product—properly and improperly made soldered joints.

A good well-bonded connection is clean, shiny, and smooth. It shows the approximate outline of the wire and terminals. The wire and terminals are completely covered, and the solder adheres firmly. The insulation is close but not in the hole or slot; it is approximately 1/8 inch from the terminal. It is not charred, burned, nicked, or covered with rosin. A film of rosin may remain on the joint and need not be removed unless the joint is in a high frequency circuit or unless fungusproofing is anticipated.

Soldered joints may be defective for a variety of reasons, such as the following:

A COLD solder joint has a dull appearance and a crystallized texture. Because of the poor union between the wire and terminal, the joint will in time develop high resistance as the metals oxidize. This type of joint is caused by insufficient heat during soldering, and may be repaired by reheating.

A ROSIN joint is so named because the wire is held by rosin rather than solder. The flux is spread over the terminal, and instead of the


TRY TO LOCATE THE TROUBLE BY OBSERVING THE CIRCUIT'S FAULTY OPERATION
1
TRY TO LOCATE THE TROUBLE BY USING EYES AND NOSE
2
LOCALIZE THE TROUBLE AT THE FAULTY MAJOR UNIT BY TESTING TECHNIQUES
3
LOCALIZE THE TROUBLE AT THE FAULTY SUBUNIT BY TESTING TECHNIQUES
4
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
5
REPLACE OR REPAIR THE DEFECTIVE PART
6
TEST THE CIRCUIT'S OPERATION---READJUST THE CIRCUIT
7

167.801

Figure 14-7.—Troubleshooting procedure.

lder bonding with the terminal, the solder ttles on top of the rosin. The joint may have l the appearances of a good joint, but a little essure will cause movement or an ohmmeter ll indicate an open. A rosin joint occurs when ing a "cold" iron or one that is too small. In ost cases, merely applying a hot iron will ear up a rosin joint.

A DISTURBED solder joint has an irregular crystallized appearance and the solder may chipped off with a fingernail or a pointed tool. is caused by the wire being moved before the lder has fully set. It may be repaired in the me manner as the cold solder joint.

An INSUFFICIENT solder joint can introduce high resistance in the circuit and, as current flows, undesirable heat. It may loosen and cause an open or intermittent operation depending upon the amount of oxide present. This heat or a visual inspection may reveal this condition, but it may be necessary to use an ohmmeter to detect this type of solder joint. To repair it, it should be taken apart; and after cleaning off the oxide, the joint should be resoldered correctly.

A NO-SOLDER joint may cause noise due to oxide or vibration; the circuit may open entirely. A visual inspection and an ohmmeter will indicate this condition. The joint should be taken apart, cleaned, and then resoldered correctly.

There are many other soldering defects, such as excessive solder, loose solder, and insulation too close or too far from the joint.

Occasionally some special techniques are required in soldering. An example is the case of fire control equipment using miniaturized components. In such equipment, the physical dimensions of resistors have greatly decreased and application of a soldering iron close to the body of these small carbon composition resistors causes a PERMANENT change in resistance. Overheating of these resistors and other components during soldering can be avoided only by restricting heat conduction along the terminating leads.

The most acceptable means of preventing this overheating is by use of a thermal shunt, (fig. 14-8). This shunt should be placed as close to the resistor and as far from the joint as possible. Be certain that the clamp does not contact both the resistor and the joint. If you don't have a clamp type shunt, and don't have time to make one, you can use small needle-nose pliers. If you wrap a rubber band tightly around the handles, the pliers will grip the resistor lead so that you won't have to hold them in place while you solder.

CRIMPING

The crimp-on solderless terminals require relatively little operator skill. Another advantage is that the only tool necessary is the crimping tool. The connections are made more rapidly; they are cleaner and more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

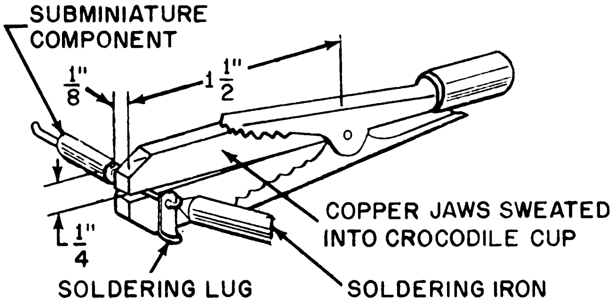


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Figure 14-8.—Details of thermal clamp type shunt.

The basic types of terminals are shown in figure 14-9. A shows the straight type, B the right angle type, C the flag type, D the splice type, and E the disconnect splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three- and four-way splice type connectors, etc.

Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated terminal; the barrel of the terminal (fig. 14-9) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

The standard crimping tool, figure 14-10, employs a double jaw to hold the terminal or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown at the left in figure 14-10. When the tool is used correctly, a deep crimp is placed in the B area of terminal lugs and splices, as shown in diagrams on the right of the figure. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as

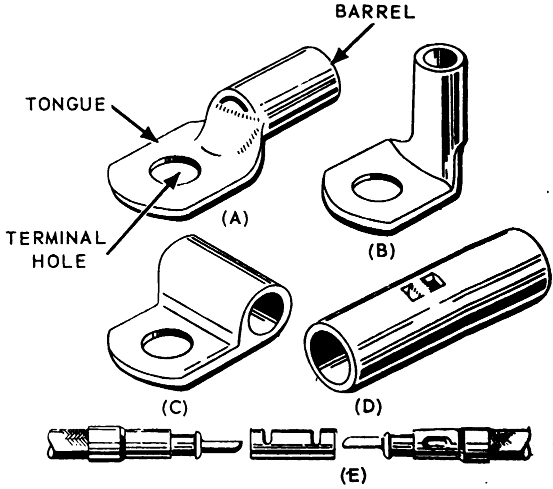

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Figure 14-9.—Basic types of solderless terminals.

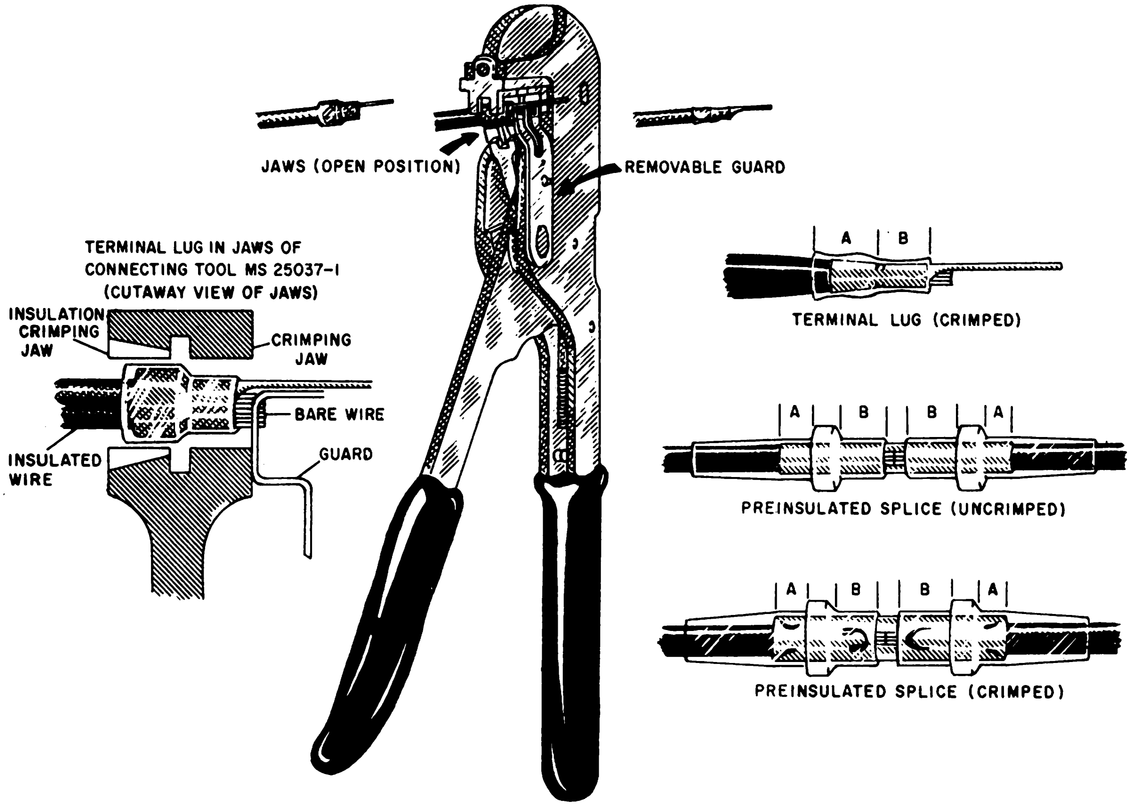

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Figure 14-10.—Crimping tool.

ndicated by the A area in the diagrams. This lamping action is provided by a recessed por- on in the other side of the divided jaw. A uard, which should be in the position shown hen crimping terminals, aids in proper posi- oning of the terminal. However, the guard ust be moved out of the way when the tool is sed for crimping splices.

ICROMAINTENANCE

Microelectronic technology by itself will not olve the maintenance problem. In spite of the reatly increased reliability, failures will still ccur. When they do, the faulty items must be olated and repaired or replaced.

With the discrete miniature component (tran- stor, resistor, capacitor, etc.), you can test dividual circuit elements and thus determine the cause of failure. Repairs can then be made by replacing the faulty component.

With the integrated circuit, replacement of an individual part is impossible because the unit is designed and exists only as a complete functional element. The maintenance process then becomes a matter of isolation and replacement of the defective "chip," "flat-pack," board, or module.

Modules

Modular assemblies are mechanically more rugged than conventional circuits. They are, however, susceptible to damage from improper handling, electrical overload, or overheating. Techniques of maintenance and servicing are similar to those used with conventional circuits, but require somewhat more care in execution.

The small size and close spacing of the parts within the assembly require more care and smaller tools than are normally required in conventional maintenance. Additional devices and maintenance aids are of great help in developing the precision needed for such close work. Many components are inherently susceptible to damage from various causes. These factors require modification of some of the basic maintenance techniques and the use of some new ones.

Component damage during maintenance is usually the result of excess heat during repair, reversed polarity of ohmmeters while checking for continuity, application of excessive voltages or signal magnitudes during testing, rough handling, or use of the wrong tools or materials.

Loosening connections, disconnecting parts, inserting or removing transistors, and changing modular units should not be done with the power on or while the circuit is under test. These actions (or a loose connection of any type) will cause an inductive kickback, which may damage the component.

It is also important to remove any capacitive charge from parts, tools, or test equipment before connecting them to any modular unit. A grounding clip should be connected from the item to the modular chassis before making any other contact. When disconnecting, the grounding clip should be removed last.

Leads to transistors, printed circuit boards, etc., as well as many miniature components, are easily damaged in handling, stowage, or shipping. Proper precautions should be used at all times.

It should be emphasized that these miniature components and circuits can be repaired, if adequate care and proper techniques are used.

PRINTED CIRCUITS

The trend toward replaceable units has led to several new methods of construction of electronic equipment, an example of which is the printed circuit. This type circuit is designed for speed and economy of manufacture, and speed and ease of maintenance, as well as the saving of space and weight.

Repair Technique

The printed circuit presents certain difficulties in soldering techniques that are not common to conventionally wired circuits. Certainly these printed circuits cannot be repaired in a careless manner; but with a little care and common sense, satisfactory repairs can be made.

Should a printed circuit become broken, it is easily repaired by placing a short length of bare copper wire across the break and soldering both ends to the print; or, if the break is small, simply flow solder across it. (See fig. 14-11.) When performing these operations, do not apply too much heat, and do not permit solder to flow to other printed areas.

The phenolic boards used for printed circuits are similar to the phenolic strips used for conventional terminal strips and mounting boards. There has been no difficulty in soldering to the metal connectors on these terminal strips and mounting boards, so there should be none in soldering printed circuits. In rare cases where excessive heat causes separation of printed conductors from the phenolic borad, repairs can be made by using jumper wires. (See fig. 14-12.)

Parts Replacement

Removal of a part from a printed circuit board without damaging the printed circuit or the associated parts requires that the soldering tool be used with precision and skill.

When it is necessary to do any unsoldering or resoldering, the pencil iron and special tips become quite useful. Use the special tips whenever possible.

Parts such as resistors and small capacitors are most conveniently removed if first cut to

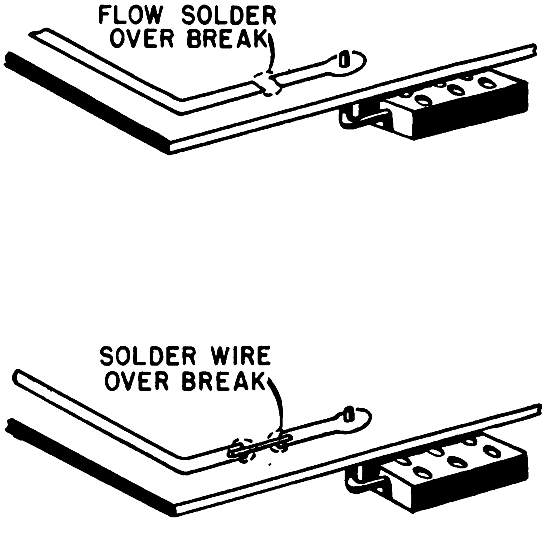

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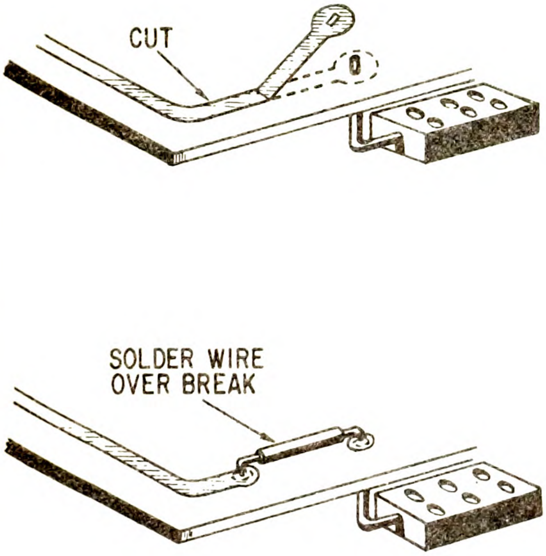
Figure 14-11.—Repairing breaks in foil.



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igure 14-12.—Repairing raised portion of foil.

ree their leads. Much less heat is required to emove a part if the leads are free. In cases here it is inconvenient to remove a board for ccess to the wiring side, it is usually possible o cut the leads of small resistors and capacitors o that a small portion of the lead is exposed. he new part can then be soldered to the old eads. This technique is shown in figure 14-13.

RANSISTOR SERVICING

There are many differences between tran- istor and electron tube circuits from the stand- oint of servicing. For instance, the reliance aced on the senses of sight, touch, and smell the visual inspection of electron tube circuits not feasible in transistor circuits. Many ansistors develop so little heat that nothing can learned by feeling them. High-frequency tran- stors hardly get warm. Usually, when a tran- stor (except a high-power transistor) is hot ough to be noticeable, it has been damaged yond repair.

In electron tube circuits, a quick test is ten made by the tube substitution method; that , by replacing the tube suspected of being bad th one known to be good. In transistor cir- its, the transistors are frequently soldered and the substitution method is impractical. Furthermore, indiscriminate substitution of transistors and other semiconductors should be avoided. It is preferable to test transistors using a transistor test set.

You studied the use of the Transistor Test Set AN/USM-206 in chapter 12, General Purpose Test Equipment and should, therefore, be familiar with the methods of testing transistors.

Voltage Checks

Voltage measurements provide a means of checking circuit conditions in transistor circuits as they do in tube circuits. The voltages in transistor circuits are much lower than in tube circuits. For example, the bias voltage between the base and emitter is in the order of 0.05 to 0.2 volts. Therefore, a sensitive VTVM is usually required. When you make voltage checks, make sure polarity is observed to avoid error in measurements. In an electron tube circuit, if you find a positive voltage on a grid, a leaky coupling capacitor is indicated. But in a transistor circuit the base to emitter voltage may be positive or negative, depending on the type of transistor. For example, the PNP type normally operates with the base negative with respect to the emitter, whereas the opposite is true of NPN transistors. Check the schematic of the circuit under test for the proper polarity as well as magnitude of voltage.

There may be time when you will want to make a current check in a circuit. In circuits that are wired in the conventional manner you

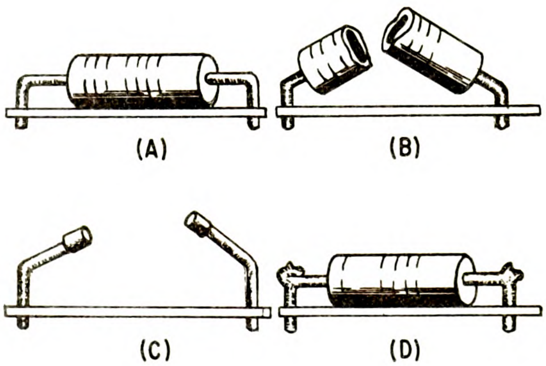

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Figure 14-13.—Replacement of a resistor on a printed circuit.

can easily unsolder a lead or remove a connection, and then place an ammeter in the circuit. With printed wiring this is not always possible. But you can calculate the current by using Ohm's law. For example, if the collector current is to be measured, measure the voltage drop across the collector resistor (load) and measure the resistor with an ohmmeter. By using Ohm's law, you can calculate the collector current.

Resistance Checks

Resistance measurements are not generally made in transistor circuits, except to check for open windings in transformers and coils. Resistors and transistors have little tendency to burn up or change value, because of the low voltage power supplies used in transistor circuits. It is important to remember that before you attempt to measure the resistance of any transistor circuit component, you must REMOVE THE TRANSISTOR OR COMPONENT. Since the ohmmeter has a battery, the wrong voltage polarity may be applied to a critical stage and cause permanent damage to the transistor. Another word of caution. Always disconnect the supply voltage before you remove a transistor from its socket. This prevents current surges that might damage the transistor.

Signal Tracing and Component Substitution

Signal tracers may be used on transistor circuits if the precautions concerning the power supplies are observed. Many signal tracers use transformerless power supplies; therefore, to prevent damage to the transistor, an isolation transformer must be used.

You can trace a signal through a transistor circuit just as you do in a vacuum tube circuit. When you find a faulty component, replace it with a duplicate.

Precautions

Although transistors are rugged, you must observe certain precautions. The leads are the most fragile part. Whether they are long and flexible or short and rigid, they should be treated carefully. When transistors with long flexible leads are soldered or resoldered, make sure you don't overheat the transistor. Use the heat-sink technique previously described. Transistors with short rigid leads are usually plugged into sockets. In some cases, however, these transistors are plugged directly into the printed board; and then dip soldered.

Transistors require low operating voltages. Small changes in these voltages can greatly upset the biasing of transistors. In some circuits, small bias changes can result in destruction of the transistor. Therefore, make sure you don't short out any circuit components. This action could disturb all the voltage relationships in the equipment, and thus destroy a number of transistors.

Conventional test prods, when used in the closely confined areas of transistor circuits, often are the cause of accidental shorts between adjacent terminals. In electron tube circuits the momentary short caused by test prods rarely results in damage, but in the transistor circuit this short can destroy a transistor. Also, as transistors are very sensitive to improper bias voltages, the practice of troubleshooting by shorting various points to ground and listening for a click must be avoided. Remember the sensitivity of a transistor to surge currents when you are testing transistor circuits.

Except for the special precautions and servicing techniques mentioned here, servicing transistor equipment should present no greater problem than servicing its electron tube counterparts.

EQUIPMENT WIRING

Wiring is identified by a system of numbers and letters attached to each wire. The OP gives the number of each wire involved in cabling of electronic equipment. Should it become necessary to trace and repair a wire, refer to the OP to determine the routing of the wire involved.

CONNECTORS

Connectors are inspected when the major units that they connect are inspected. During this inspection, the mating parts of the connectors are separated and the contacts examined for corrosion. If corrosion is present, the surfaces are cleaned with a brush or clean rag and a noncorrosive solvent. The coupling ring is inspected for battered threads, and should be replaced if the threads are not in good condition. When attaching or detaching the connector, care should be taken to avoid damaging the coupling or bending the coupling nut.

If the connector does not contain a moisture- oofing compound, the conductors should be spected where they are soldered to the pin ntacts. Short circuits are often caused by a ayed strand of one conductor touching the lder cup of another conductor within the plug. this is the case, the frayed strand may be ipped. Check to see that all soldered connec- ons are adequate and that no cold solder ints exist.

Connectors do not require lubrication ex- pt for the coupling ring threads. Occasionally, ey should be given a light coat of antiseize mpound to insure smooth operation.

NDUCTORS AND TERMINALS

Although modern technical literature has en emphasizing the use of printed circuits d microelectronic components in contempo- ry electronic equipment, conductors are still portant as a signal- or current-carrying vice. (For the purpose of this discussion the rm conductor will refer to both wire and ble.) As a significant part of operating equip- ent, conductors deserve appropriate attention.

ire

For wire replacement work, the OP for the uipment should first be consulted since it rmally lists the wire used. When this information cannot be obtained from the OP, the pairman must select the correct conductor eded for the job. The three major factors volved in this selection in descending order importance, are size, insulation, and the aracteristics required to satisfy specific vironments in which the wire must function.

CONDUCTOR SIZE.—For d.c. applications, allowable voltage drop and current-carrying pacity govern the choice of size. At radio- quencies, the skin effect and inductance may come a controlling factor, although generally cept in inductors or RF transformers) these ameters need not be considered. Wire size therefore basically a function of the current the allowable resistance, except when this ults in a very small conductor size.

Small conductors are difficult to handle and subject to breakage in soldering or due to ration. Experience has shown that these iculties may be avoided by using No. 22 or 24 AWG for general circuit wiring and at st No. 20 AWG for parallel connected tube filaments. Solid wire should be used only for short jumper connections not exceeding 3 inches in length, unless the parts being connected are solidly mounted and not subject to vibration. Clamps or "dress lugs" are recommended for long leads. In other words, the use of stranded copper wire whenever possible is strongly recommended, although under extreme conditions of vibration or where high flexibility is required, oxygen-free copper is sometimes specified. Copperclad steel is another possibility for applications requiring greater strength and rigidity.

INSULATION.—A wide variety of insulating material is available, which makes its specification particularly important. Since each insulation has its peculiar characteristics, no single type is always suitable for general usage. The major insulation requirements include good dielectric strength, high insulation resistance (internal and surface), wide temperature range (with high softening and low brittle points), flexibility, color stability, and resistance to abrasion, crushing, moisture, fungus, burning, radiation, oil, and acids.

Insulation requirements for electronic, as opposed to power, applications are somewhat more exacting due to the higher frequencies and impedances and often high voltages involved. Insulation resistance and dielectric strength are the prime considerations, although for RF application the figure of merit (capacity to Q ratio) becomes important.

Some of the insulations used for general hookup wire include lacquered cotton, high temperature rubber, butadiene styrene copolymers, Celanese, fiberglass, nylon, vinyl, polyvinylchloride, cellulose acetate, polystyrene, polyethylene, Teflon, and various silicon-treated materials. An insulation wall thickness of not less than 0.013 inch is recommended for all wiring within the confines of an enclosure or where mechanical protection is provided. Where wiring is exposed or subject to wear or abrasion, heavier insulation is required.

ENVIRONMENTS.—Environmental factors such as temperature, humidity, vibration, radiation, fungus, contaminants, and corrosive elements must be taken into consideration. These requirements are included as a part of the specification for the equipment where the wire is to be used.

Terminals

Since most wires are stranded, it is necessary to use terminal lugs to hold the strands together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring diagram for the particular models. Soldered and crimped type terminals may be used interchangeably, but both must have the same amperage capacity and the same size hole in the lug.

Cable Splicing

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

SHIELDING AND BONDING

Shielding is the enclosing of cables or electrical units in metal to prevent high frequency interference. Shielding causes the high frequency voltage to be induced in the shield rather than in the units or cables. Shielding is used where a unit is to be protected from radiofrequency noise. It is also used to keep cables or units from emitting radiofrequency noise.

Where shielding of cables is used, it is very important that it be well grounded. Radiating circuits such as pulse cables and transmission lines use coaxial cables. The outer flexible conductor of "coax" often serves as the shield, but occasionally an additional braid is used for shielding. Regardless of the system used, the conductor forming the shield is grounded.

Disturbances caused by spark discharges are the most difficult to control. A spark discharge not only radiates but also causes voltage variations in the circuit. Shielding is effective for the radiations but not for line variations. These variations in the line can be smoothed out by the use of filters. The function of such filters is to block or bypass voltages and currents of frequencies which would cause interference.

Bonding straps are used to tie together, electrically, any parts of an equipment or system which are insulated from the ship's structure. Some of the reasons for bonding are:

1. To minimize interference to electronic equipment by equalizing the static charges that accumulate.
2. To provide a proper "ground" for electronic equipment.
3. To provide a low resistance return path for single-wire electrical systems.
4. To aid in the effectiveness of shielding.

A bond is usually made of a flexible metal strap provided with a crimped-on terminal a each end.

The bond must be intact and make a good electrical connection at all times. In replacing a bond, be careful to make a good metal contact Place bonds in such a position that they will no interfere with the operation of the unit and will not be damaged or broken loose because of the motion or vibration of the unit.

SHOCK MOUNTS

Electronic equipment is sensitive to mechanical shock and vibration; therefore, units o electronic equipment are normally shock mounte to provide some protection against vibratio

Periodic inspection of shock mounts is required, and defective mounts should be replace with the prescribed type. In the inspection, th main factors are chemical deterioration of th shock absorbing material, stiffness and resili ency of the material, and overall rigidity of th mount.

Shock absorbing materials commonly use in shock mounts are usually electrical insula tors. For the sake of safety, it is required th each electronic unit mounted in this manne must be electrically bonded to a structur member of the ship. (See fig. 14-14.) The bondi

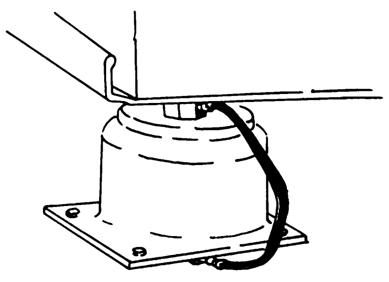

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Figure 14-14.—Shock mount, bonding.

strap should also be included in the inspection of the shock mounts, and defective or ineffective bonds should be replaced or reinstalled.

SAFETY WIRING

Some equipment parts require a positive safety locking device. The use of safety wire is one accepted method of providing this safety measure. The two most common applications of safety wire are the tying together of nuts, bolts, screws, and connector parts to prevent them from coming loose due to vibration.

The most common method of safetying nuts, bolts, and screws is known as the double-twist method. The twisting may be accomplished by hand, or the special safety wire pliers may be used. (See fig. 14-15 (A).) If the twists are made by hand, the final few twists should be made with pliers to apply tension and secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to ensure that they are tight but not overstressed to the point where breakage will occur under a slight load or vibration. Always use new safety wire on every job and take care to use pliers only on the ends of the wire so as not to nick the wire. If safety wire becomes nicked, discard it and use a new piece. When the final twists are made with pliers, cut off the loose ends that have been nicked by the pliers and bend the end of the wire around the bolt or screw head to protect personnel from the sharp ends.

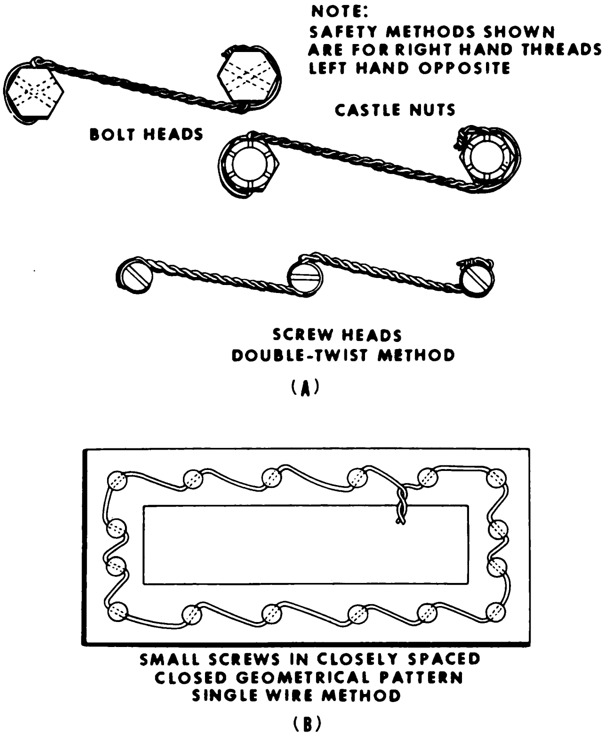

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Figure 14-15.—Safety wiring nuts, bolts, and screws.

The single wire method of safety wiring (fig. 14-15 (B)) may be used on small screws in a closely spaced area provided the screws form a closed geometrical pattern. Note that any loosening tendencies will pull against the tension of the wire. Never "back off" or overtorque in order to align holes for safety wiring.

Safety wire electric connectors only when specified on engineering drawings or when experience has shown the connector will not stay tight. Electric connectors are usually safety wired in engine nacelles, areas of high vibration, and in locations not readily accessible for periodic maintenance inspection.

When it is necessary to safety wire electrical connectors, use 0.032-inch diameter wire wherever possible. On small parts with holes 0.045-inch nominal diameter wire or smaller, use 0.020-inch diameter safety wire. If the connector to be safety wired does not have a wire hole, remove the coupling nut and drill a No. 56 (0.046-inch diameter) hole diagonally through the edge of the nut. Figure 14-16 shows a properly safety wired connector.

GENERAL MAINTENANCE

At the beginning of this chapter, it was noted that you must develop skill and knowledge, of a general nature, to perform your maintenance tasks. Soldering techniques, for example, are not explained in detail in your system and equipment OP's. But there are many times when you will have to make soldered connections to keep your systems in good operating order. Similarly there are other maintenance actions you will have to accomplish. Therefore,

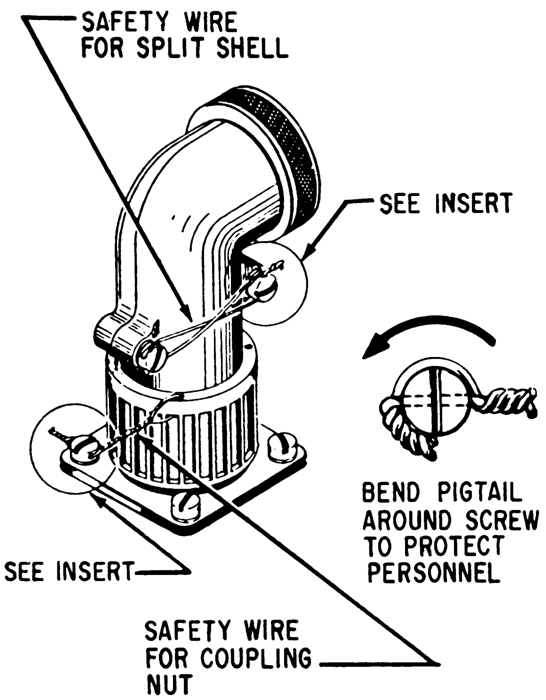
SAFETY WIRE FOR SPLIT SHELL
SEE INSERT
BEND PIGTAIL AROUND SCREW TO PROTECT PERSONNEL
SEE INSERT
SAFETY WIRE FOR COUPLING NUT

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Figure 14-16.—Safety wiring a connector.

let's discuss some of these general maintenance procedures.

CLEANING AND LUBRICATING MECHANICAL PARTS

Many mechanical computing devices used in fire control equipment are highly machined and are close tolerance mechanisms. The accuracy of the fire control system is often dependent upon the operation of these mechanical devices. Dirt, dust, or other foreign particles will cause the system to operate inaccurately. Moisture may cause corrosion which may also cause inaccuracy. Excessive wear will cause inaccuracies and shorten the life of the equipment. Thus, it can easily be seen that cleaning, lubricating, and moistureproofing of close tolerance parts is necessary to have accurate effective equipment.

Most mechanical equipment is enclosed in a dustproof housing. If you use reasonable precautions, the dust problem in this equipment is small. Before you remove a cover, be sure the surrounding area is clean and that all likely sources of dust have been eliminated. A major source of dust is the ventilation system. When working on precision equipment such as a computer, the ventilation system should be secured. If you cannot secure it, cover the blower duct openings with cheesecloth or gauze.

If a unit is removed from its housing and taken to a shop or other working area, adequate provisions must be made to keep the mechanisms clean and dry. Before the unit is disassembled, all dirt, dust, grease, and other foreign matter must be removed from its outside surface. The working surfaces of the unit, and the components or subcomponents to be worked on, must be as clean and dry as circumstances permit. Whenever the unit is disassembled, all components and subcomponents must be kept under lint-free dust covers (cloths) to protect them from foreign matter.

Cleaning

Even when the previous precautions are taken, some dirt and other foreign matter may penetrate into the equipment. Also, it may be necessary to remove excessive or old oil and grease. The correct solvent MUST be used since some solvents leave a residue or cause corrosion. Therefore, ALWAYS check the OP.

Spraying or splashing of the solvent must be avoided during cleaning. If the solvent were to fall upon a bearing surface, it would cut the lubricant or render it less effective, causing excessive wear. After the solvent has been used, the parts must always be wiped dry with a clean lint-free cloth.

Lubrication

Lubricants are used to reduce friction between moving parts. Occasionally, lubricants are used for the purpose of preventing rust, oxidation, and corrosion. The applicable maintenance manual includes the lubrication instructions for the particular equipment. But no lubrication procedure will be effective unless it is performed regularly. Different components must be lubricated at different intervals; the recommended frequency of lubrication for each component must be followed.

Lubrication instructions indicate the type and amount of lubricants, lubrication points, and frequency of application. In addition, the instructions may contain other maintenance functions to be performed in conjunction with lubrication. Don't trust your memory; follow a checkoff list with a systematic schedule.

Do not overlubricate your equipment. Excessive lubricant acts as an insulating blanket and prevents the dissipation of heat. Overfilling or overheating may cause overflow into adjacent electrical equipment. Lubricants generally deteriorate electrical insulation materials.

Cleanliness is important in lubrication. Dirt in a lubricant makes a damaging abrasive material. Plastic protective caps are provided for some types of grease fittings. Lubrication points must be cleaned prior to lubrication. If a cleaning solvent is used, it must be wiped dry before the lubricant is applied.

CLEANING AND LUBRICATING ELECTRONIC EQUIPMENT

Most electronic equipment has a serious dust problem. This is a direct result of the heat problem. Heat is dissipated by air taken into the unit and circulated. Air filters are installed, but they are not 100 percent effective. The housing is not dustproof, so you can expect to find some dust in electronic units.

You should clean electronic units frequently. To clean an electronic assembly, use a soft brush and a vacuum cleaner with a nonmetallic hose. Keep in mind that even though the power is off, dangerous potentials may still be present.

Avoid using a portable blower or a compressed air hose to clean a cabinet or chassis. Dust may be blown into relay contacts or open switches. Oil inside the cabinet will usually be caused by a leaky oil-filled capacitor, which should be found and replaced.

Air filters must be cleaned periodically. They are often neglected or disregarded until excessive heating causes a breakdown of the equipment. Accumulated dust is removed by hosing the filter with soapy water. The filter is then dried and replaced in its holder.

Ceramic insulators should be kept clean to prevent leakage and possible arc-overs. If wiping with a clean cloth is not enough, a cloth moistened with an approved solvent may be used. The insulator is then polished dry with another clean cloth.

Ferrule resistors and fuses should be removed from their clips, and corrosion or dirt removed from the components and clips. Use a cloth dipped in solvent, or if necessary, fine sandpaper or crocus cloth to remove the dirt.

Electronic equipment is more than an arrangement of vacuum tubes, transistors, and other electronic units. Its operation depends upon a number of moving mechanical parts. Many of these parts require lubrication at regular intervals. The OP for each electronic equipment gives the lubrication instructions. Lubrication techniques are the same for electronic equipment as they are for mechanical equipment.

INSPECTIONS

To prevent the likelihood of future troubles or malfunctions, you must make visual inspections of your equipment. In the following paragraphs we will point out some of the things you should look for.

Routine visual inspection of terminal boards should be made and terminal screws checked for tightness. A loose terminal lug can cause an intermittent malfunction of equipment that may be difficult to find. It is important not to overtighten terminal screws because you may strip the threads. Loose terminal lugs are a common source of trouble because they work loose due to normal ship vibration.

Cables should be inspected for looseness or damage at places where they enter equipment or at any other point in a cable run. Cables showing signs of damage or abuse should be either rerouted or protected. Particular attention should be given to the coaxial cable, which is easily damaged by dents or sharp bends.

Look for signs of overheating and faulty insulation. When these signs appear, the equipment will be blackened around the area of overheating. Check the condition of tubes and tube sockets. Sometimes vibration loosens the tubes in their sockets.

The air screens of amplidyne motors and motor generator sets should be inspected and kept cleared of dirt and dust. Excessive vibration of these units is a danger signal of faulty operation. The most usual causes are loose mounting bolts, shaft misalignment, and foreign matter rubbing the rotating element.

Inspect junction boxes, exposed radar compartments, and other unit covers to see that they are properly dogged down. Tighten all retaining bolts and dogs evenly and firmly, alternating between diametrically opposite bolts or dogs.

ROTATING MACHINERY MAINTENANCE

Rotating machinery should be inspected and cleaned at prescribed intervals (periodic checks) and whenever repairs to the machinery have been made. For such cleaning and inspection, the following procedure is suggested.

1. Unfasten and remove end cover.
2. Remove dust and dirt from machine and end covers, using clean, dry compressed air or a soft brush.
3. Loosen, gently remove, and inspect brushes, being extremely careful not to nick or mar their edges. Note the location and position from which each is removed so that it can be replaced in exactly the same position.
4. Check commutators or sliprings for excessive wear, pitting, dirt, thrown solder, or other defects. A highly polished commutator or slipring is desirable, but a dark-colored one should not be mistaken for a burned one. If the surface is dirty, clean with a lint-free cloth moistened in a cleaning solution and wipe dry. Avoid fingermarking the commutator or slipring surface.
5. Secure all brushes in their holders, making certain they are replaced in exactly the position from which they were removed.
6. Replace and secure end covers.

Sliprings

Sliprings are solid metal rings mounted on the rotor of alternating current machines for transferring the power to or from external circuits through brushes or wipers. Sliprings are also used on synchros, director connections, and stable element connections.

While they vary in size and type, the maintenance of sliprings is essentially the same for all types. They should be inspected periodically for wear, grooving, and cleanliness. Normally, the surface of the rings should be bright and smooth.

As mentioned previously, the connection to the rings is by brushes or wipers. Wiper contacts are used with devices that do not require high current and consequently require only light pressure when making contact. Excessive pressure will result in excessive wiper wear, because the wiper contact is usually of a softer material than the rings. Any contacts showing considerable wear should be replaced.

If sliprings are inspected and found rough, scratched, or grooved, corrective action must be taken. They can be smoothed with a fine crocus cloth or sandpaper. However, care should be exercised not to cause high and low spots which will interfere with high speed operation. Further repairs, such as cutting with a lathe, should be performed at overhaul activities (Navy yards and tenders). Also in cleaning with a solvent, be careful not to allow the solvent to enter the bearings since the solvent will cut oil or grease. This, of course, will cause the lubricant to flow out of the bearing.

Commutators

Commutators have been called the "soft spot" of d.c. machinery because they require considerable maintenance. The commutator is a series of copper segments separated by an insulator. When the brushes make contact with a pair of segments, an armature coil is connected into the circuit. Thus when the motor or generator is moving, the brushes and commutator switch coils in and out in the proper sequence.

The normal appearance of the commutator is a shiny, smoothly worn, chocolate brown color. A blackened or pitted commutator is caused by poor brush and segment contact, open or shorted coils, overloads, etc. If the brushes are causing the blackened appearance, they should be replaced and then the commutator should be cleaned. Cleaning is accomplished by the use of fine sandpaper and the recommended solvent. The sandpaper should be held against the commutator by a piece of wood that is grooved to fit the commutator. NEVER USE EMERY CLOTH. Emery is an electrical conductor, which will cause a short circuit.

If the fault is other than brush and segment contact, that is, a short or open coil, the machine should be replaced and sent to overhaul. Another fairly common defect is HIGH MICA. As the copper of the commutator wears down, the mica, which is the insulation separating the segments, does not. Consequently, it may be higher than the segments. The high mica gives a bounce to the brush every time it passes underneath; this results in arcing because the brush is constantly breaking contact. High mica can be spotted by rubbing your fingernail over the surface of the commutator. There should be a small depression between each segment. If there is high mica, this depression disappears. Undercutting is the remedy for high mica, and this operation is normally reserved for the overhaul activities.

Brushes

Brushes are found in numerous sizes and shapes and are made of various materials and compounds. Many brushes used in fire control equipment are made of a composition of graphite and other forms of carbon. In all probability the majority of the maintenance you will perform on rotating machinery will be concerned with brushes. Brushes should be checked for wear, chipping, oil soaking, sticking in the brush holders, spring tension, length, and area of contact with the commutator. If for any reason a brush is removed and is to be replaced, it should be marked or tagged so it may be replaced in the same brush holder in the same position it occupied before removal.

Brushes that show excessive or improper wear or chipping, or are oil soaked, should be replaced. Care should be exercised in obtaining the correct replacement. It is important that the brushes be changed before they are completely worn away to prevent damage to the equipment in which they are used.

Some brushes are marked to indicate allowable wear by a readily noticeable groove in their edge. This groove extends from the top of the brush down to a point that is 75 percent of the brush wearing depth. (The top is the end opposite the wearing face.) Thus if the brush is worn down to the groove, it must be replaced. If no groove is present, consult the equipment OP for acceptable minimum brush lengths.

In the replacement of brushes, you will find that some new brushes are ready to use. That is, the brush face is slightly concave so that it fits tightly on the commutator. However, because other new brushes are NOT ready for use, they must be sanded in. This sanding, or seating, can be accomplished by wrapping fine sandpaper around the commutator. The paper is placed sand side up with a lap following the direction of normal rotation of the device, and is held in place by a rubber band. Do NOT use glue or tape. The brushes are placed in their holder under spring tension, and the armature is rotated slowly by hand in the direction of normal rotation. In so doing, the contact surfaces of the brushes are sanded until their curved surfaces match the curvature of the commutator. The carbon dust from the brushes must be removed from the device by using dry compressed air followed by cleaning with solvent.

CLEANING OPTICAL LENSES

An optical instrument with components of the highest quality arranged in the best design possible is of little or no value if vision through it is obscured by dirty optics.

The items you will normally need for cleaning optical elements include a small brush (camel's hair), alcohol, lens tissue (soft, lintless paper), and absorbent cotton or silk floss. To this list you may also wish to add a special lintless cloth for cleaning optics, the best type of which is velvet cloth.

The recommended procedure for cleaning glass optics is presented by steps in the following paragraphs:

1. Brush the surface of the lens with a brush (camel's hair) using quick, light strokes.

2. If the lens is large, use several pads of lens tissue dampened with alcohol to remove remaining dirt and/or grease. Change cleaning pads or swabs frequently enough to prevent damage to the optic by dirt or grit. Use a cotton, silk, or floss swab, or lens tissue on small lenses.

3. As you clean an optic, swab lightly with a rotary motion, working from the center to the edges. Avoid excessive rubbing to prevent damage to the coating of an optic and charging with static electricity.

ENVIRONMENTAL PROBLEMS

The environmental factors that should be understood to maintain the design characteristics include temperature, humidity, pressure, and abrasive conditions.

TEMPERATURE

Extensive research has been conducted to develop external component parts that are better able to withstand operation under extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility of rubber, insulation, and similar materials. Extremely high temperatures may cause deformity and deterioration of these items. Most internal component parts are not able to withstand these extreme temperatures.

Because equipment is normally installed in confined spaces aboard ship, the generated heat causes the temperature to rise; therefore, many units have fans installed to increase the air circulation, thus reducing the temperature within the unit.

HUMIDITY

Humidity, a measure of water content in the air, is a possible cause of equipment or component failure. High humidity (that is, a high water content in the air) provides a possible environment for corrosion and fungus growth. A high moisture content in the air may cause short circuiting between points of high potential.

In certain cases the removal of heat from equipment requires the use of external air. If this external air has a high moisture content, the cooling may be accomplished by one of two ways. First, the high humidity air may be directed through an air jacket which surrounds the equipment. In this case the heat is removed without allowing the humid air to come in contact with the internal equipment components. Second, when the internal equipment components require direct air for heat removal, the direct air is passed through silica-gel crystals, removing the moisture from the air. It should be apparent that the second method is less troublesome because the first case does cause corrosion within the air jacket.

PRESSURIZATION

When high voltage electrical equipment is operated, there is always the problem of arcing. To reduce the possibility of arcing, the case of the equipment is pressurized. Thus, all components inside the case are subject to pressurization, and the possibility of arcing is minimized. In the case of radar operation at high altitudes, the waveguides and parts of the antenna are also pressurized.

Pressurization is usually not a big maintenance problem, but on occasions will cause trouble. The troubles that do arise in the pressurization system are usually the result of poor preventive maintenance. To have a trouble-free pressure system, all seals and gaskets (located at the points of separation, waveguide joints, and case covers) must be very carefully installed to provide an airtight seal. When pressurization troubles do occur, they may be difficult to detect since a very small leak is normally all it takes to render the system inoperable. Before attempting to put the system under pressure for checking for leakage, first consult the OP. This is necessary since each system has certain specifications concerning the amount of pressure that may be safely applied. If excessive pressure is applied, it could possibly rupture the seals or gaskets, or even cause mechanical damage to parts of the equipment.

ABRASIVE CONDITIONS

Sand, dust, and other substances which are abrasive in nature affect many components. Generally these components are parts that are not sealed off from the atmospheric conditions. In some cases the abrasive material is formed even though the unit is sealed. Examples are generators, motors, and dynamotors which use brushes. Also the protective coating may be removed from a part by the movement of the abrasive material in the air that is used for cooling. This may allow the unprotected metal to corrode.

Modern configurations employ air-conditioning systems for the purpose of cooling the equipment. The external air is used to cool the heat exchanger while the internal air used to remove heat from the equipment may be pressurized. The use of the pressurized air for equipment heat removal minimizes the undesired environmental effects of temperature, humidity, arc-over, and abrasive conditions.

SHOCK AND VIBRATION

Vibration effects are directly related to the resonant mechanical frequency of the equipment. A reduction of shock and vibration effects may be obtained by locating the heavier components as close as possible to the mounting points to reduce the length of the moment arm.

The extended use of miniaturization and printed circuits will, to some extent, counteract the troubles due to increased accelerations and shocks that military electronic equipment is now encountering.

CORROSION CONTROL

The need for corrosion control has become a major concern in the availability and maintenance of our striking forces. This is because corrosion destroys equipment and is active 24 hours a day.

MOISTURE PREVENTION

The battle against moisture is never-ending. Moisture creeps into the smallest openings.

Watertight covers must be kept watertight. When you remove a cover, check the condition of the gasket, the knife edge, and the securing bolts or dogs. Where possible, when checking an electrical circuit, use a connection box in a protected space. When moisture is discovered in an instrument or connection box, dry it out with a hot-air blower or an electric lamp.

A reasonable degree of protection against the accumulation of moisture is obtained by a daily energizing and workout of the equipment.

Variations in temperature cause air to be breathed through any opening or vent in the equipment. As the temperature rises, the air inside a piece of equipment expands and is partly expelled. When the temperature falls, the air inside the equipment contracts and outside air is admitted. As the air cools, condensation or sweating takes place. Electrical heaters are installed in some instruments to eliminate this source of moisture. The heater keeps the interior of the instrument at a temperature higher than that of the surrounding air. In many instruments, the circuit to the heater bypasses the power switch, and voltage may be present even though the power switch is off. Remember this when vorking around the heater circuit.

Some equipment may use an air drier, or lesiccator unit, to moistureproof the mechanisms vithin the unit. The unit is sealed by dust covers and is airtight except for the connection o the air drier. The air drier consists of a unit that contains silica gel crystals. The silica gel crystals absorb moisture from the air within he unit.

Salt and Fungus Treatment

Salt and fungus found in your equipment should e removed immediately. Salt, when moisture is resent, will corrode metals and is a conductor f electricity. Fungus growth causes decay, rapid eterioration of insulating materials, and shorts r grounds in electrical circuits. Under some ircumstances you can use fresh water to renove it. After cleaning the equipment, however, nake sure the water is completely evaporated. cleaning solvent, methyl chloroform, can be sed to clean away salt or fungus. But methyl hloroform will attack electrical insulating maerials, and contact time should be limited. igh concentration of methyl chloroform vapor an be dangerous to life. Adequate ventilation s necessary when it is used.

SAFETY PRECAUTIONS

Much has been written on safety precautions. Consequently, the number of accidents which occur in the Navy is small. Most of the safety precautions applicable to Missile Fire Control Technicians are published in system and equipment OP's. Many of the safety regulations included in these OP's and other technical manuals are the result of actual experiences, so give them careful consideration.

CAUSES OF ACCIDENTS

There are four closely related causes of accidents: CARELESSNESS, INEXPERIENCE, OVERCONFIDENCE, and FATIGUE.

Carelessness

CARELESSNESS is something most human beings have to overcome. You have to cultivate good working habits—you must learn to coordinate your mental and physical actions to a point where you can concentrate on the important parts of the job at hand without having to worry about the minor mechanical functions pertaining to it.

Inexperience

INEXPERIENCE can be the cause of accidents regardless of how careful the individual intends to be. The best solution to this problem is NEVER GUESS—you must learn to ask questions about things you are unfamiliar with or are not completely sure about. Beginners have a tendency to be overeager and desire to put their hands to work. Eagerness is a good trait in any person, but you must realize that men with more experience usually know best. Work into a job gradually and be particular about thoroughness; always be conscious of correct procedures in doing things. Train your mind and hands to function correctly so as to protect yourself and others from physical injury. For example, when you work with a screwdriver, be sure that your left hand (or right hand, if you are left-handed) is clear of the screwdriver bit; otherwise, a slip of the screwdriver may drive the bit completely through your hand or may gouge deep into your arm. If you practice correct methods from the start, they'll become automatic before you realize it.

Overconfidence

OVERCONFIDENCE can come to both young and old, experienced and inexperienced; however, it is usually more closely associated with inexperience. Often, however, men grow overconfident when they become thoroughly familiar with a particular job, and have a tendency toward carelessness. To put it briefly, always be confident that you know a job, but beware of overconfidence because it may invite mistakes which can cause accidents.

Fatigue

FATIGUE has always been the cause of a large percentage of accidents. You might be highly efficient when you have energy to burn, but it's another story when you get tired; your physical actions slow up and become inaccurate. Always prepare yourself for the task ahead by learning how much endurance it requires, and then get the necessary sleep, recreation, food, and exercise to keep on your toes. Remember, to be alert and to feel your best is extremely important on the job, and you can only enjoy this feeling by keeping yourself in good physical condition.

ELECTRIC SHOCK

Electric shock may cause burns of varying degree, cessation of breathing and unconsciousness, ventricular fibrillation or cardiac arrest, and death. If a 60-hertz alternating current is passed through a person from hand to hand or from hand to foot, the effects when current is gradually increased from zero are as follows:

1. At about 1 milliampere (0.001 ampere) the shock will be felt.
2. At about 10 milliamperes (0.01 ampere) the shock is severe enough to paralyze muscles and a person may be unable to release the conductor.
3. At about 100 milliamperes (0.1 ampere) the shock is usually fatal if it lasts for one second or more. IT IS IMPORTANT TO REMEMBER THAT FUNDAMENTALLY, CURRENT, RATHER THAN VOLTAGE, IS THE CRITERION OF SHOCK INTENSITY.

It should be clearly understood that resistance of body will vary. That is, if the skin is dry and unbroken, body resistance will be quite high, on the order of 300,000 to 500,000 ohms. However, if the skin becomes moist or broken, body resistance may drop to as low as 300 ohms. Thus, a potential as low as 30 volts could cause a fatal current flow. Therefore, any circuit with a potential in excess of this value must be considered dangerous.

IT SHOULD BE NOTED AT THIS POINT THAT THE TAKING OF AN INTENTIONAL SHOCK IS PROHIBITED BY NAVY REGULATION.

Care of Shock Victims

Electric shock is a jarring, shaking sensation resulting from contact with electric circuits or from the effects of lightning. The victim usually experiences the sensation of a sudden blow, and if the voltage is sufficiently high, unconsciousness. Severe burns may appear on the skin at the place of contact; muscular spasm can occur, causing a person to clasp the apparatus or wire which caused the shock and be unable to turn loose. Electric shock can kill its victim by stopping the heart or by stopping breathing, or both. It may sometimes damage nerve tissue and result in a slow wasting away of muscles that may not become apparent until several weeks or months after the shock is received.

The following procedure is recommended for rescue and care of shock victims.

1. Remove the victim from electrical contact at once, but DO NOT ENDANGER YOURSELF. This can be done by: (1) throwing the switch, if it is nearby; (2) using a dry stick, rope, leather belt, coat, blanket, or any other nonconductor of electricity; or (3) cutting the cable or wires to the apparatus, using a damage control ax while taking care to protect your eyes from the flash when the wires are severed. Even the victim's shoes, if dry, can be used to pull him clear.
2. Determine whether the victim is breathing. If so, keep him lying down in a comfortable position. Loosen the clothing about his neck, chest, and abdomen so that he can breathe freely. Protect him from exposure to cold, and watch him carefully.
3. Keep him from moving about. After shock, the heart is very weak, and any sudden muscular effort or activity on the part of the patient may result in heart failure.
4. Do not give stimulants or opiates. Send for a medical officer at once and do not leave the patient until he has adequate medical care.
5. If the victim is not breathing, it will be necessary to apply artificial respiration without delay, even though he may appear to be lifeless.

Artificial Respiration

Artificial respiration, the mechanical promotion of breathing, is used to resuscitate persons whose breathing has stopped as a result of electric shock, drowning, asphyxiation, strangling, or the presence of a foreign body in the throat. To revive perons suffering from electrocution resulting in stoppage of breathing, begin artificial respiration immediately. Send another person for competent medical aid. If there is any serious bleeding, stop it first, but do not waste time on anything else. Seconds count; the longer you wait to begin, the less are the chances of saving the victim.

For complete coverage on administering artificial respiration and treating burns, refer to Standard First Aid Training Course, NAVPERS 10081-B.

GENERAL SAFETY PRECAUTIONS

Although many specific safety precautions are laid down for you in the OP's and technical manuals, there are a few general precautions which you should remember. Let's start by discussing the handling of handtools and power tools.

Handling Tools and Machinery

Many accidents occur because of the improper handling of tools. In general, these accidents occur in the form of physical injury to the person operating the tools. The following list gives the more important general precautions to follow:

1. Whenever chipping, buffing, or grinding with handtools and power tools, always wear goggles as a protection to the eyes. Little chips from a spinning grind wheel, or a bristle from a revolving wire brush can easily put out an eye. Many of these machines are provided with a guard: be sure to use it.

2. Always ground the provided ground lead located at the plug of portable tools such as electric drills to protect yourself from shock in case a ground occurs within the tool.

3. When working with sharp handtools, always work so that the tool is moved or thrust away from the body.

4. Never wear loose clothing or a neckerchief when working with rotating tools or machinery. Such clothing may become caught in the spinning parts and drag you bodily into the machine causing severe physical injury.
5. Never use metal handtools on energized electrical equipment or circuits because you may get shocked, or the tool may cause a short circuit causing molten copper to be blown into your face and eyes.
6. Never use handtools around running machinery, nor perform adjustments to running machinery unless absolutely necessary.
7. Never lay handtools on top of running machinery where vibration may cause the tool to fall into exposed working parts.
8. If it is necessary to work on electric equipment that is in an energized state, wear rubber gloves, use tools, with insulated handles, and stand on an insulated mat. Always work with one hand to prevent the possibility of a circuit through your body from arm to arm.
9. When working with tools, always work in a physically comfortable position, and keep the weight of your body well centered.

Electrical Work

The following list is in addition to those precautions on handtools and machinery, and is applicable to all electrical work. This list will help you prevent electric shock or burns during daily work.

1. Do not block high voltage protective cutout on doors or covers to keep the circuit energized with the cover off. It is intended that work be performed on such electrical equipment while the circuit is deenergized.
2. Always ground the provided ground lug located at the plug of portable tools such as electric drills to protect yourself from shock in case a ground occurs within the tool.
3. Always be sure that all condensers are fully discharged before commencing work on a deenergized high voltage circuit. Use an insulated shorting bar for this purpose.
4. Tag the switch OPEN (open the switch and place a tag on it stating "This circuit was ordered open for repairs and shall not be closed except by direct order of .") at the switchboard supplying power to the circuit on which you wish to work. When possible, remove the fuses protecting the circuit and place them in your tool box for safekeeping until the job is complete.

5. Always remove fuses with fuse pullers and never remove fuses, until after opening the switch connecting the circuit to the source of supply. Never replace a fuse with one LARGER than the circuit is designed to take.

6. Utmost caution should be observed when inspecting behind an open-back switchboard in an energized state.

7. Never use an incandescent test lamp unless its voltage rating is greater than the highest voltage which may be tested.

8. Always test a supposedly deenergized circuit with a voltage tester before commencing work on the circuit.

9. Never work on an electric circuit or network without first thoroughly acquainting yourself with its arrangement and with its points of power feed.

10. Never work alone on electrical equipment. Always have someone present to render first aid in case of emergency.

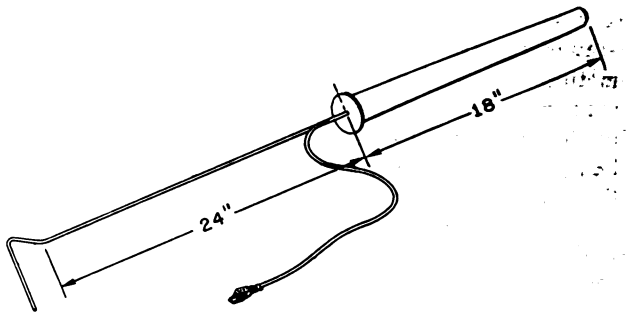
Common Safety Features in Electronic Equipment

You should be aware of the safety features that are generally included in electronic equipment. Some of the common safety features are interlock switches, bleeder resistors, current-limiting resistors, insulating controls, and powerline safety devices such as fuses. Keep in mind that these features cannot always be counted on to function. Don't develop a false sense of security just because an equipment has safety features.

Safety Shorting Probe

ALWAYS ASSUME THAT THERE IS A VOLTAGE PRESENT when working with circuits having high capacitance even when the circuit has been disconnected from its power source. Therefore, capacitors in such circuits should be discharged individually, using an approved type shorting probe. High capacity capacitors may retain their charge for a considerable period of time after having been disconnected from the power source. An approved type shorting probe is shown in figure 14-17.

When using the safety shorting probe, always be sure to first connect the test clip to a good ground (if necessary, scrape the paint of the grounding metal to make a good contact). Then hold the safety shorting probe by the insulated handle and touch the probe end of the shorting rod to the point to be shorted out. The probe end is fashioned so that it can be hooked over the part or terminal to provide a constant connection by the weight of the handle alone. Always take care not to touch any of the metal parts of the safety shorting probe while touching the probe to the exposed "hot" terminal. It pays to be safe; use the safety shorting probe with care.



1.1

Figure 14-17.—An approved type shorting probe.

Some equipments are provided with walk-around shorting (such as fixed grounding studs or permanently attached grounding rods). When this is the case, these should be used rather than the safety shorting probe described previously.

RADIOACTIVE ELECTRON TUBES

Electron tubes containing radioactive material are now commonly used. These tubes are known as TR, ATR, PRE-TR, spark-gap, voltage-regulator, gas-switching, and cold-cathode gas-rectifier tubes. Some of these tubes contain radioactive material and have intensity levels which are dangerous; they are so marked in accordance with Military Specifications.

So long as these electron tubes remain intact and are not broken, no great hazard exists. However, if these tubes are broken and the radioactive material is exposed, or escapes from the confines of the electron tube, the radioactive material becomes a potential hazard. The concentration of radioactivity in a normal collection of electron tubes in a maintenance shop does not approach a dangerous level, and the hazards of injury from exposure are slight. However, at major supply points, the storage of large quantities of radioactive electron tubes in a relatively small area may create a hazard. For this reason, personnel working with equipment employing electron tubes containing radioactive material, or in areas where a large quantity of radioactive ubes is stored, should read and become thoroughly amiliar with the safety practices contained in Radiation, Health, and Protection Manual, NAVMED P-5055. Strict compliance with the prescribed safety precautions and procedures of this manual will help to avoid preventable accidents, and to maintain a work environment which is conducive to good health.

The following precautions should be taken to ensure proper handling of radioactive electron ubes and safety of personnel:

1. Radioactive tubes should not be removed rom cartons until immediately prior to actual nstallation.
2. When a tube containing a radioactive material is removed from equipment, it should be placed in an appropriate carton to prevent possible breakage.
3. A radioactive tube should never be carried n one's pocket, or elsewhere on a person in such a manner that breakage can occur.
4. If breakage does occur during handling or emoving of a radioactive electron tube, notify he cognizant authority and obtain the services f qualified radiological personnel immediately.
5. Isolate the immediate area of exposure to rotect other personnel from possible contaminaion and exposure.
6. Follow the established procedures set forth n NAVMED P-5055.
7. Do not permit contaminated material to ome in contact with any part of a person's body.
8. Take care to avoid breathing any vapor r dust which may be released by tube breakage.
9. Wear rubber or plastic gloves at all times luring cleanup and decontamination procedures.
10. Use forceps for the removal of large fragnents of a broken radioactive tube. The remainng small particles can be removed with a acuum cleaner, using an approved disposal ollection bag. If a vacuum cleaner is not availble, use a wet cloth to wipe the affected area. n this case, be sure to make one stroke at a ime. DO NOT use a back-and-forth motion. fter each stroke, fold the cloth in half, always olding one clean side and using the other for the ew stroke. Dispose of the cloth in the manner tated later.
11. No food or drink should be brought into e contaminated area or near any radioactive aterial.
12. Immediately after leaving a contaminated rea, personnel who have handled radioactive aterial in any way should remove any clothing ound to be contaminated. They should also thoroughly wash their hands and arms with soap and water, and rinse with clean water.
13. Immediately notify a medical officer if a wound is sustained from a sharp radioactive object. If a medical officer cannot reach the scene immediately, mild bleeding should be stimulated by pressure about the wound and the use of suction bulbs. DO NOT USE THE MOUTH, if the wound is of the puncture type, or the opening is small, make an incision to promote free bleeding, and to facilitate cleaning and flushing of the wound.
14. When cleaning a contaminated area, seal all debris, cleaning cloths, and collection bags in a container such as a plastic bag, heavy wax paper, or glass jar, and place in a steel can until disposed of in accordance with existing instruction. Decontaminate all tools and implements used to remove a radioactive substance, using soap and water. Monitor the tools and implements for radiation with an authorized radiac set; they should emit less than 0.1MR/HR at the surface.

CATHODE-RAY TUBES (CRT's)

Cathode-ray tubes should always be handled with extreme caution. The glass envelope encloses a high vacuum and, because of its large surface area, is subject to considerable force caused by atmospheric pressure. (The total force on the surface of a 10-inch CRT is 3750 pounds, or nearly two tons; over 1000 pounds is exerted on its face alone.) Proper handling and disposal instructions for CRT's are as follows:

1. Avoid scratching or striking the surface.
2. Do not use excessive force when removing or replacing the CRT in its deflection yoke or its socket.
3. Do not try to remove an electromagnetic type CRT from its yoke until the high voltage has been discharged from its anode connector (hole).
4. Never hold the CRT by its neck.
5. Always set a CRT with its face down on a thick piece of felt, rubber, or smooth cloth.
6. Always handle the CRT gently. Rough handling or a sharp blow on the service bench can displace the electrodes within the tube, causing faulty operation.
7. Safety glasses and gloves should be worn when handling CRT's.

CLEANING SOLVENT

The Navy does not permit the use of gasoline, benzine, ether, or like substances for cleaning purposes. Only nonvolatile solvents should be used to clean electrical or electronic apparatus.

In addition to the potential hazard of accidental fires, many cleaning solvents are capable of damaging the human respiratory system in cases of prolonged inhalation. The following is a list of ''Do Nots'' when using cleaning solvents.

1. DO NOT work alone in a poorly ventilated compartment.
2. DO NOT breathe directly the vapor of any cleaning solvent for a long time.
3. DO NOT spray cleaning solvents on electrical windings or insulation.
4. DO NOT apply solvents to warm or hot equipment, since this increases the toxicity hazard.

The following reminders are positive safety steps to be taken when cleaning operations are underway.

1. Use a blower or canvas wind chute to blow air into a compartment in which a cleaning solvent is being used.
2. Open all usable portholes, and place wind scoops in them.
3. Place a fire extinguisher close by, ready for use.
4. Use water compounds in lieu of other solvents where feasible.
5. Wear rubber gloves to prevent direct contact.
6. Use goggles when a solvent is being sprayed.
7. Hold the nozzle close to the object being sprayed.

Inhibited methyl chloroform (1,1,1 trichloroethane) should be used where water compounds are not feasible. Methyl chloroform is toxic and should be used with care since concentrations of the vapor can be fatal. Methyl chloroform is an effective cleaner and safe when reasonable care is exercised. Care requires plenty of ventilation and observance of fire precautions.

For additional information on the safety precautions to be observed when using solvents, see chapter 9670 of the NAVSHIPS Technical Manual.

AEROSOL DISPENSERS

Deviation from prescribed procedures in the selection, application, storage, or disposal of aerosol dispensers containing industrial sprays has resulted in serious injury to personnel because of toxic effects, fire, explosion, and so on. Specific instructions concerning the precautions and procedures that must be observed to prevent physical injury cannot be given because there are so many types of industrial sprays available. However, all personnel concerned with the handling of aerosol dispensers containing volatile substances should clearly understand the hazards involved and the need to use all protective measures required to prevent personal injury. Strict compliance with the instructions printed on the aerosol dispenser will prevent many of the accidents which result from improper application, mishandling, or improper storage of industrial sprays used in the Naval service for electrical and electronic equipment.

SAFETY IS YOUR JOB—DO IT PROPERLY!

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